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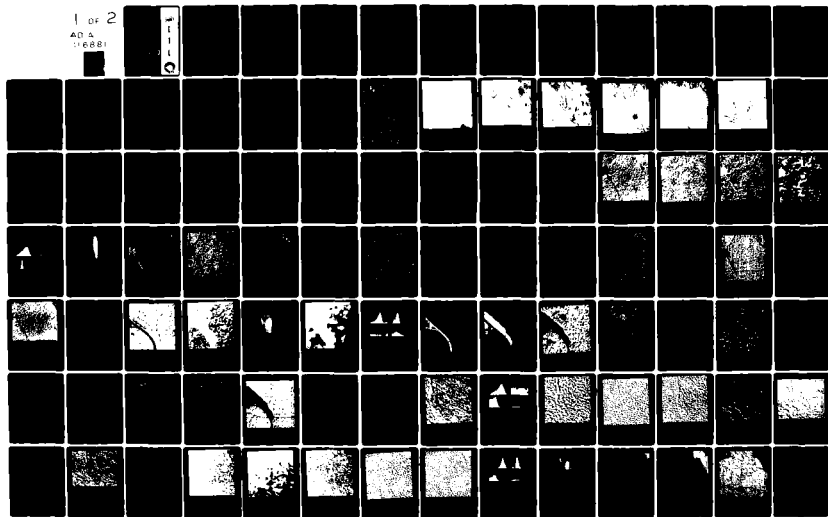
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Interactive digital image
processing for terrain
data extraction, phase 3

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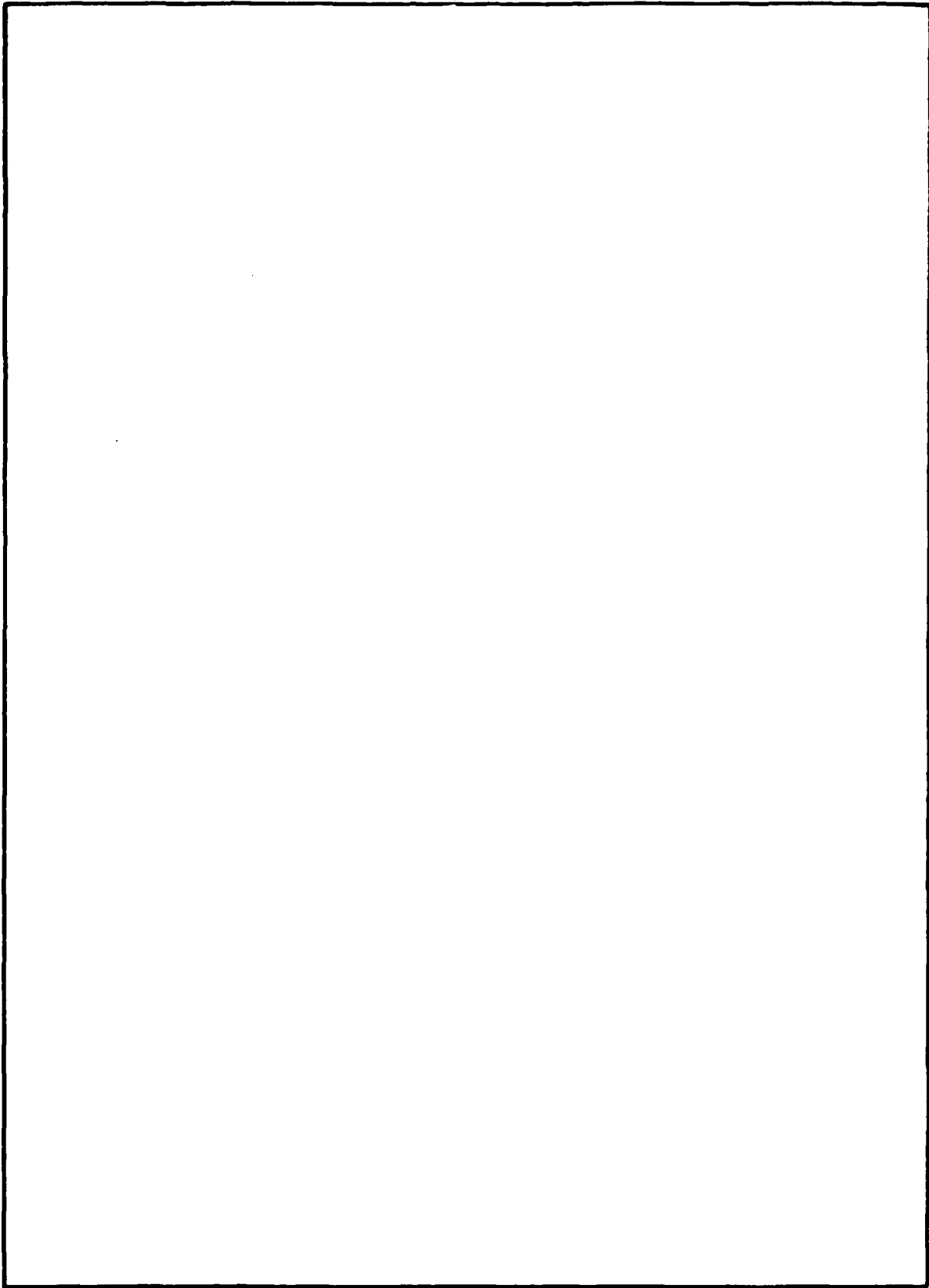
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INTERACTIVE DIGITAL IMAGE PROCESSING FOR TERRAIN DATA EXTRACTION

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PREFACE

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I. INTRODUCTION

A. Background

Phase 1 and 2 of the experimental study "Interactive Digital Image Processing for Terrain Data Extraction" have concentrated on the feasibility and use of man-machine interactive digital processing techniques for the extraction of terrain data elements from aerial imagery. Interactive digital techniques were developed for vegetation/land cover boundary extraction and for extraction of forest-related data elements. These techniques included the use of spatial crown and texture operators.

Applications of these operators during Phase 1, enabled the extraction of feature roughness at several scales; extraction of vegetation types, wet areas and water bodies; and the determination of forested areas, forest canopy and locations of individual trees. The overall success of Phase 1 suggested the need to further test the operators relative to water resources data element and to improve the test the spatial crown and texture operators at different scales.

The development and coding of software included programs in image resolution and scale changing, feature skeletonizing, and theme smoothing. These programs were implemented on the GE DIAL system, primarily in Fortran language. Limited testing of the programs was completed in Phase 2 to demonstrate usefulness. The implementation of these programs on systems similar to GE DIAL, is feasible.

The extraction of water resources data elements required the outlining

of features such as vegetation boundaries and shore line delineation of water bodies. Through spatial binary processing, or Golay processing, features were quickly and flawlessly outlined.

A slight variation of outlining, peripheral line stripping, provided a feasible, but somewhat lengthy (multiple pass) means of categorizing watercourses by the width of their manually mapped dry gaps. Terminal points of water course segments were located by one pass Golay processing. Efforts to delineate watercourses, the prime water resources element, were only partially successful. The seemingly simple problem was to connect separated pixels of a watercourse theme, and then shrink or skeletonize the feature into a single pixel width centerline. Satisfactory delineation was achieved for certain cases but no universally applicable techniques were found.

The production of usable factor overlays, which is the desired result of terrain element extraction, was addressed and handled by writing what is thought to be an important theme filtering program. Its basic purpose was to perform spatial low pass filtering on a categorized image as required to generate overlays which resemble those made by photointerpretation and which are spatially simple enough to be combined into complex overlays. Provisions are made to restrict change of critical or exceptionally accurate themes and to remap on a spatial basis those which are incidental or plagued with categorization errors.

Further testing of the techniques software were recommended as a result of the Phase 1 and 2 work.

B. Objective

The objective of Phase three was to evaluate for a variety of scene conditions the forest element extraction techniques developed in the previous phases of the study.

C. Scope

The scope of Phase three included the interactive analysis of digitized black/white panchromatic aerial images of forested areas selected by USAETL. Forest element extraction techniques were applied and revised accordingly for various scene conditions provided by selected images. Comparison and evaluation of extracted results were made with USAETL collected ground truth and with manual photo interpretation methods.

II TEST SITE INFORMATION AND IMAGERY USED

In the Phase three study, six test sites were used. Five of the sites were located in the Ft. Belvoir area and one site in a national forest of unknown location. Figure 1, a map of the Ft. Belvoir area defines five sites where field measurements were made to establish ground truth. In Figures 2 through 7 digitized segments of aerial photographs corresponding to the ground truth sites are defined. The Forest Service photograph is shown in figure 8. Table 1 contains information pertaining to the ground truth sites, and Table 2 lists information relative to the imagery used and to the image digitization process.

TABLE 1 - GENERAL INFORMATION OF SITES

SITE DESCRIPTION	LOCATION	DESCRIPTION OF FOREST AT SITE
A	Ft. Belvoir	Mature stand, uniform density, deciduous, some coniferous
B	Ft. Belvoir	Mature and in-mature slands, non-uniform denisty, deciduous
C	Ft. Belvoir	Mature stand, uniform density, deciduous
D	Ft. Belvoir	Mature stand, uniform density, mixture of deciduous and coniferous
Pine 1	Ft. Belvoir	Mature stand, uniform density, coniferous, mature deciduous
Forest Service 1	?	Coniferous trees of variable size.

TABLE 2

SUMMARY OF IMAGERY USED

DIGITAL DATA TAPE IDENTIFIER	DATA COLLECTION SITE IDENTIFIER	QUANTIZATION*	SCALE	FILM TYPE	COMMENTS
STEM 3	SITE C	TRANSMISSION	1:10,000	PANCHROMATIC NEGATIVE	10/1972
STEM 7	SITE A	DENSITY	1:10,000	COLOR TRANSPARENCY	10/1972
STEM 8	SITE B	DENSITY	1:10,000	COLOR TRANSPARENCY	10/1972
STEM 9	SITE B	DENSITY	1:10,000	COLOR TRANSPARENCY	10/1972
STEM 10	(FOREST SERVICE)	DENSITY	1:12,000	COLOR IR TYPE 2443	FOREST SERVICE
STEM 13	SITE D	DENSITY	1:10,000	PANCHROMATIC NEGATIVE	10/1972
STEM 14	PINE 1	DENSITY	1:12,000	TRANSPARENCY COPY OF PAN NEGATIVE	WINTER IMAGE 3/1980
STEM 15	SITE A	DENSITY *25.4 mm aperture 25 mm sample and scan separation	1:12,000	TRANSPARENCY COPY PAN NEGATIVE	WINTER IMAGE 3/1980

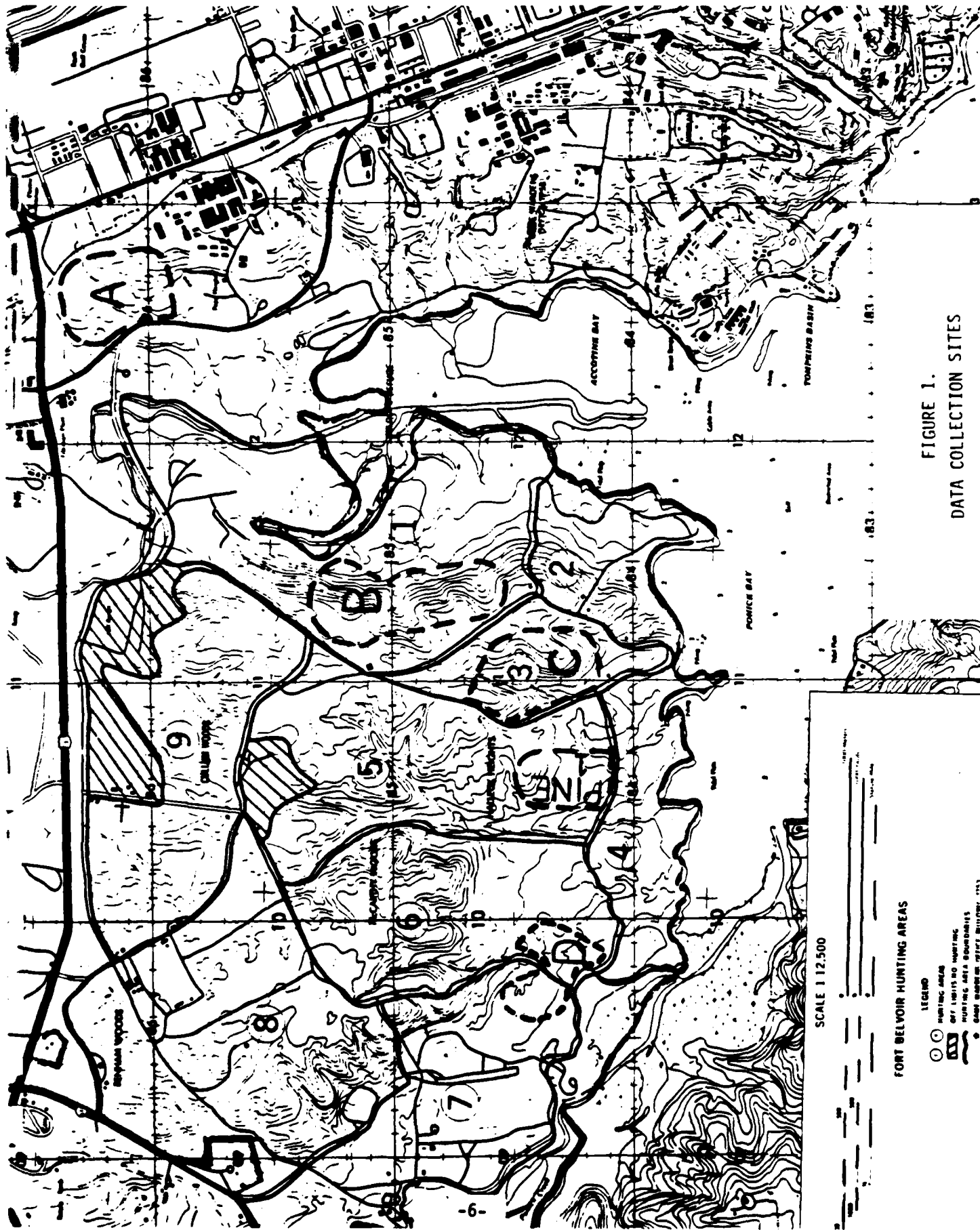


FIGURE 1.
DATA COLLECTION SITES

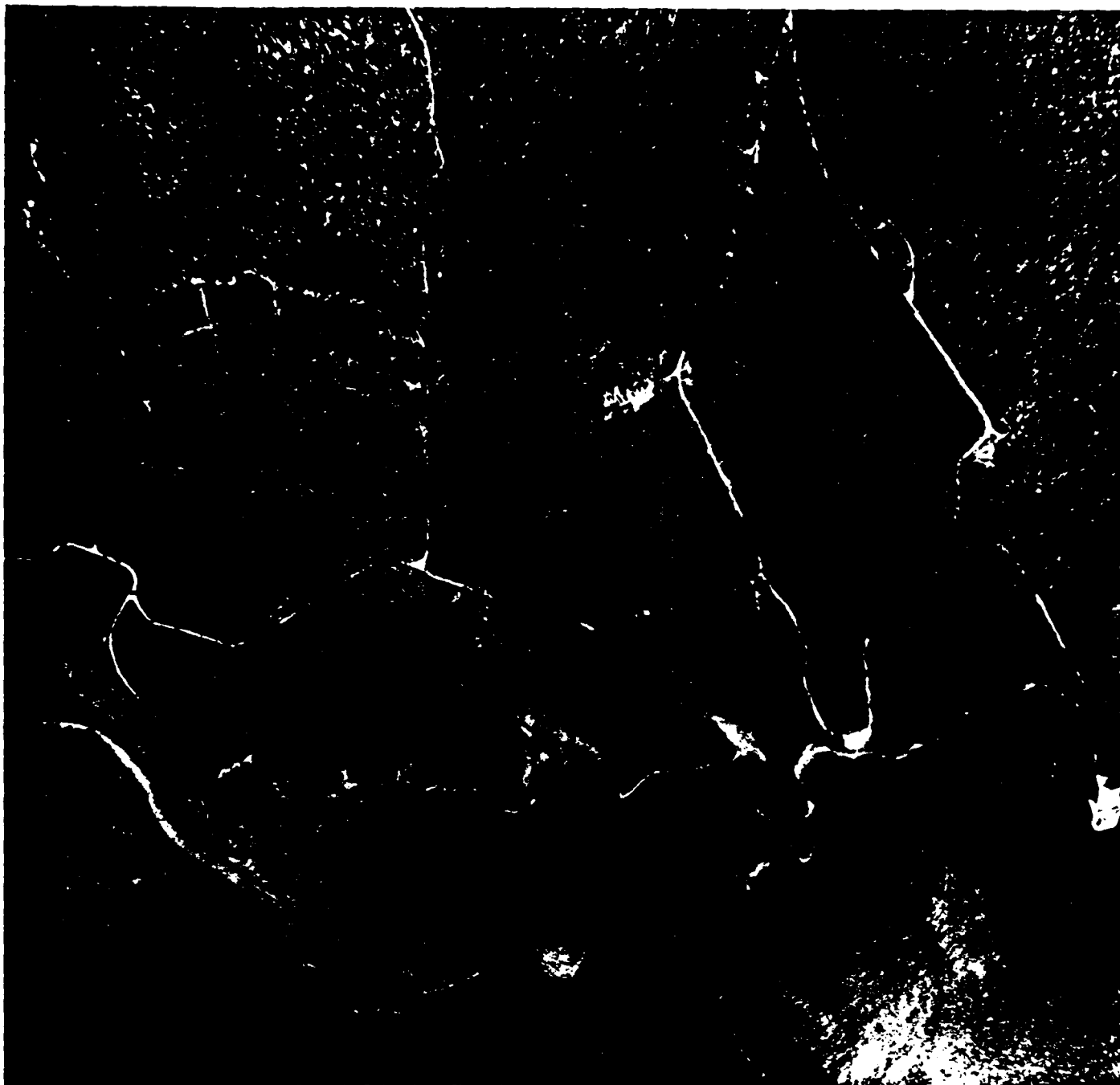


FIGURE 2
LOCATIONS OF "STEM 3" AND "STEM 13"
DIGITIZED AREAS



FIGURE 3
LOCATION OF "STEM 7" DIGITIZED AREA

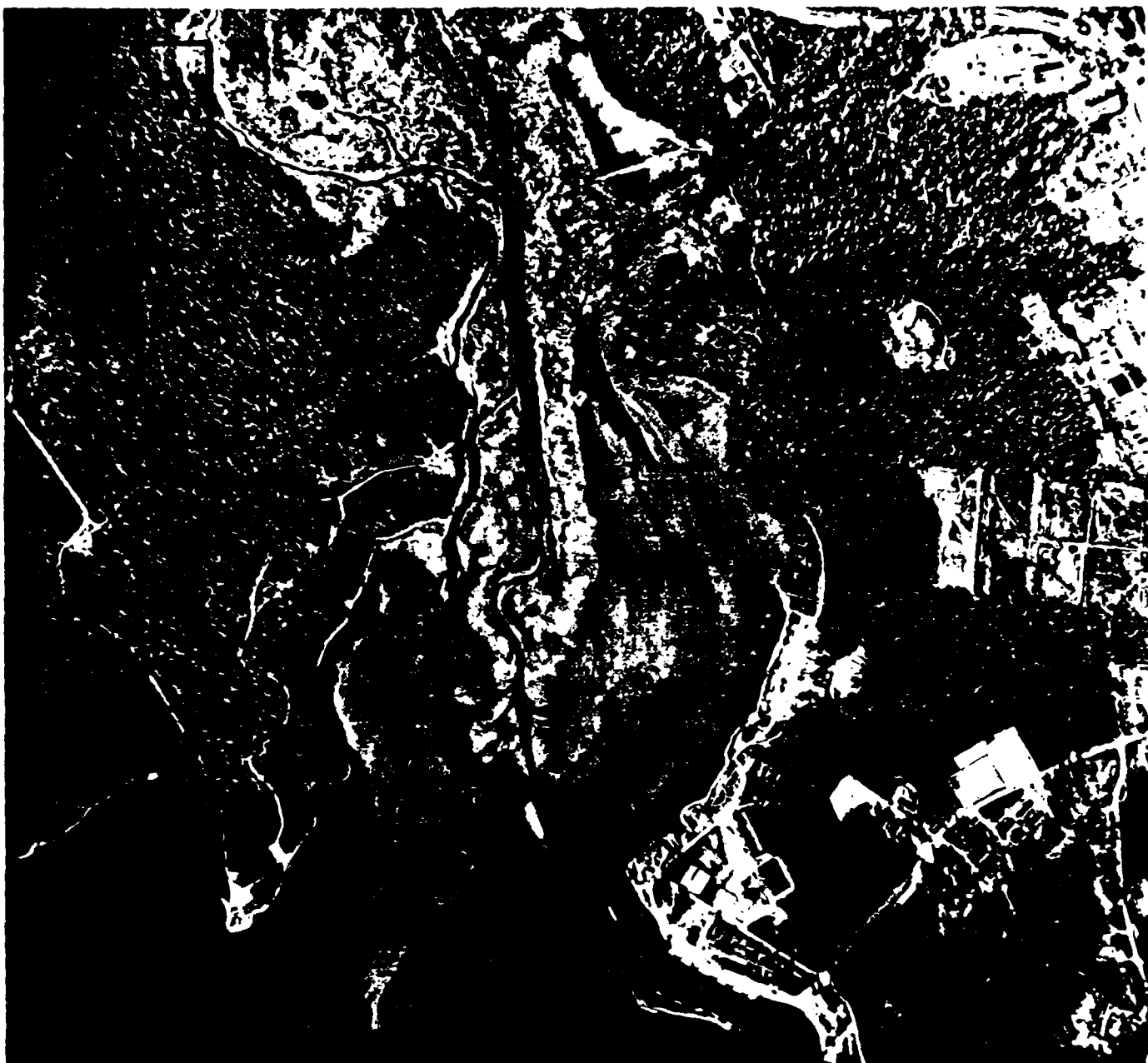


FIGURE 4
LOCATION OF "STEM 8" AND "STEM 9"
DIGITIZED AREAS



FIGURE 5
LOCATION OF "STEM 15" DIGITIZED AREA

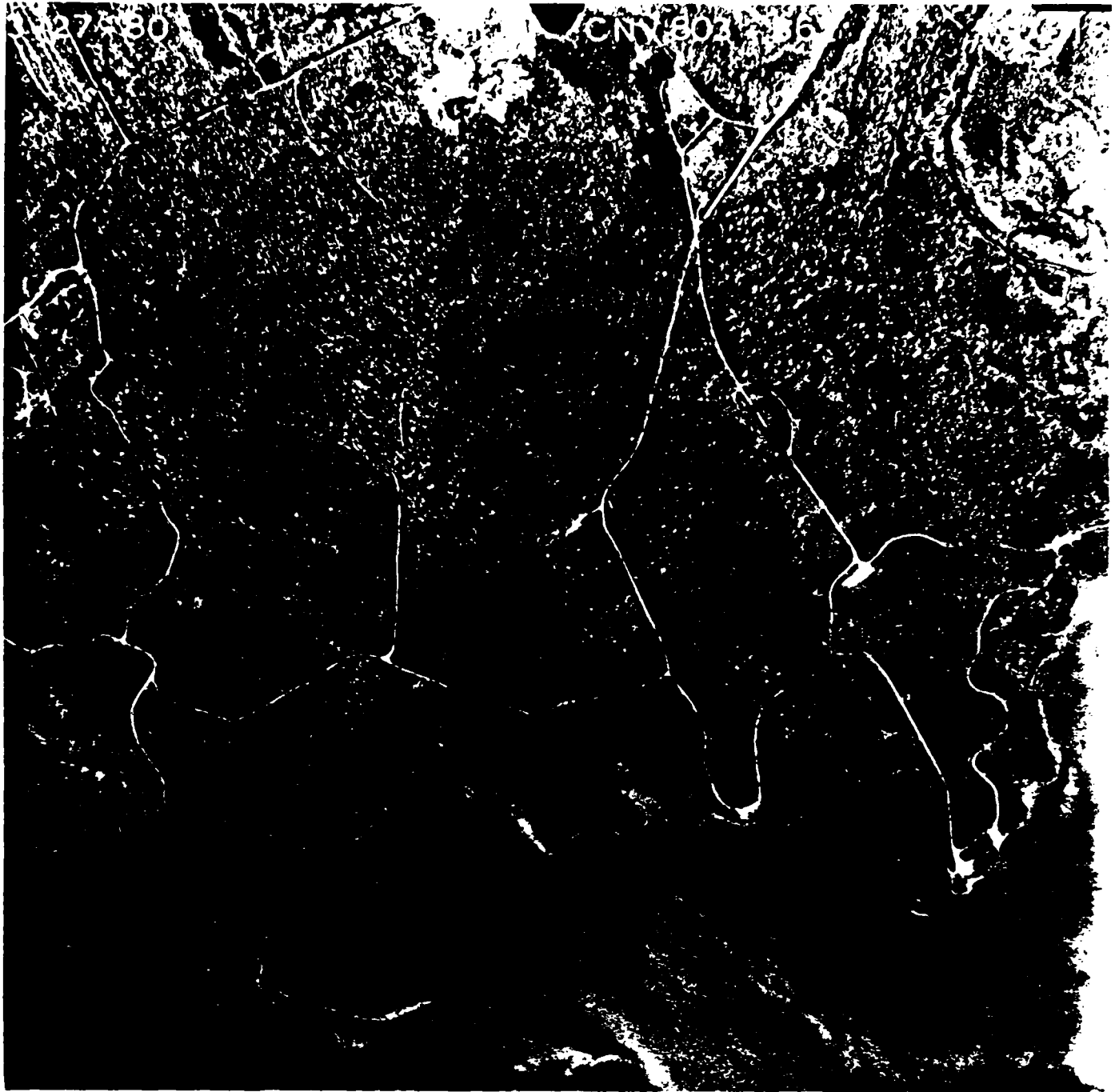


FIGURE 6
LOCATION OF "STEM 14" DIGITIZED AREA

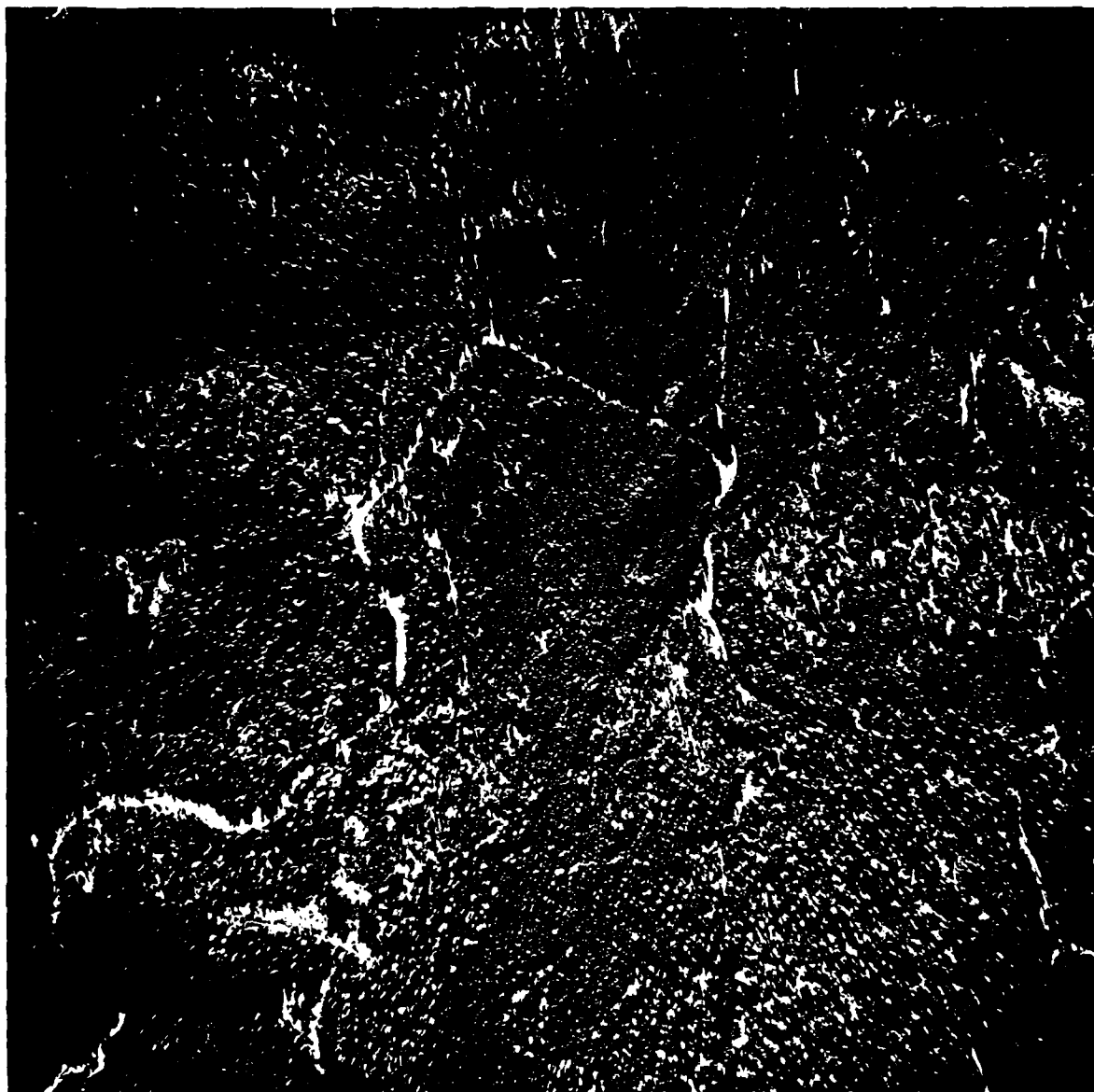


FIGURE 7
FOREST SERVICE IMAGE
WITH LOCATION OF "STEM 10" DIGITIZED AREA



III. PROCESSING TECHNIQUES

The basic processing philosophy as described in previous project phases remained unchanged, however, with some of the test sites several new and difficult problems were encountered. Several data sources were used in this phase, each supplying a new set of conditions and problems. Digitization methods had to be changed to better suit different film types, and several preprocessing steps were added to allow successful mapping of the more difficult scenes. The net result is a slightly revised process which is more widely applicable. The most difficult single problem encountered was that several of the sites showed less clear definition of individual tree crowns than any previously studied images.

A. Image Digitization

Digitization was done at USAETL on a scanning microdensitometer. A relatively slow process, but one vastly superior to using other devices such as video cameras. Quantization was performed in density units to a precision of twelve bits, on the microdensitometer. Values were then reduced to eight bits to be compatible with the image processing system used. No real loss of measurement accuracy was introduced by this operation. Quantization of photographic density to more than 8 bits is not very meaningful. Digitizing apertures of 25.4 microns were used, generating pixels of about 3 meters in size. This resulted in a digital resolution about twice as high as the minimum required for analysis.

1. Problems Encountered In Digitization

For the first few scenes analysed, the data were recorded in transmission units for analysis. This proved to be a serious procedural error. The

reason for using transmission values was to make the images appear on the interactive display with contrast similar to that which a photo interpreter might observe on a light table. The idea had worked well in previous analysis of digitized panchromatic film so no changes were thought to be necessary. In retrospect, working with transmission values is a satisfactory approach for low contrast images with a low average density. More generally, transmission values become inappropriate when high contrast films are being digitized, because an insufficient number of digital levels occur in the more dense sections of an image. The worst encountered example of this was with the Forest service test site. This particular image was at least a second generation copy of a color infrared transparency and had excessive contrast. The net result was only a few distinct transmission values left in the eight bit scale and the data were unusable. Ultimately, only one digitized area, "Stem 3" was processed in transmission units.

Another digitization problem was encountered with the "Stem 14" and "Stem 15" digitized areas. Initially, the areas were digitized from black and white contact printed negatives of a color Ektachrome transparency. The resulting digital values were very noisy. Here the grain size appeared to be about the same as the microdensitometer aperture size causing severe errors in density measurements. Digitizing black and white films containing light scattering silver particles which exhibit diffuse density, is always a compromise on a focusing densitometer, an instrument which measures specular density, and the measurements can be very poor when large grains fill the aperture. The scenes in question were ultimately reordered as color transparencies and redigitized.

B. Forest Categorization

- The concept of categorizing monochrome imagery by multidimensional classification in a data space defined by image grey level and extracted texture at a few critical scales has held up well with the more extensive testing of this phase of the project. The basic method, as outlined in earlier project phases remains largely unchanged. For those images tested, categorization was accomplished with two dimensional classification with only one derived textural image being necessary. In a working situation, images are surely to be encountered containing a more diverse mix of vegetation communities, and additional derived textural images will be required. The key point is to use derived textural images where the dominant spatial frequency gives the feature being categorized a unique character. For forest classes this is the intercrown shadow frequency.

Categorization is accomplished by simple interactive level slicing in the derived data space where "signatures" are the intersection of slice intervals. Accurately mapped categories are desirable, but not totally necessary. Very noisy categories are usable as long as the proper theme is predominant wherever the associated feature occurs. Categories are also made to identify the ever present shadow areas, and other unclassifiable pixels.

1. Theme Filtering Procedure

Spatial theme filtering is the process which makes poorly classified themes useage. During testing on various images an interactive sequence has evolved which works quite well. This procedure starts with a small filter, typically 3 x 3 pixels, applying mild smoothing to any finely structured or accurately classified themes that might exist. These well defined themes are then restricted from alteration during subsequent operations. A second pass is made over the undefined themes with a larger filter, typically 11 x 11 pixels to spatially resolve the nuisance classes. During this operation the shadows and unclassified pixels are flagged for replacement by the locally dominant class. Finally a general and severe overall smoothing is done with an 11 x 11 pixel filter to simplify vegetation themes to the point where they can be satisfactorily depicted by an outline. More than one iteration is often required for the final filtering.

2. Improvements in Categorization Procedure

One procedural improvement involved more extensive use of very low pass filtering applied to categorize difficult scenes. Several of the scenes were characterized by low contrast within the forested areas with few if any distinct crown shadows because of high solar elevation angle. When texturally based feature extraction was applied to these cases, the derived textural images were made more useful by applying a box

filter to severely low pass textural information. For the difficult scenes where the isolation of forested areas is required, it is useful to remove from the textural image, all spatial frequencies greater than a few trees in wavelength and apply a 25 x 25 pixel filter. Filtering was often done in a two pass manner to eliminate along-scan and across-scan artifacts that are often introduced by box filtering. The filter sizes used in more recent efforts represent a considerable increase over the 7 x 7 pixel circular convolution used in earlier analysis. At these very low resolutions, the textural images are dominated by image variance caused by inter-tree shadows, smoothing over individual trees. This appears to minimize the effect of mixed tree species, while still serving as a good forest descriptor. Isolated trees, or small groups of trees are also smoothed, but these should not be categorized as forest anyway. Thus, the severe filtering does not degrade the resulting theme.

3. Forest Canopy Theme

The canopy theme, critical to subsequent stem size analysis requires very little additional effort once the forested areas have been classified. In most cases this theme falls out as a by-product of the processing necessary to effectively categorize the forest. Taking the filtered forest theme and logically combining it with the shadow theme via an "EXCLUSIVE OR" operation generates a theme containing only the canopy. Minor interactive adjustment of the grey level threshold used to isolate shadow areas can be made to improve the canopy theme. Such an adjustment is recommended for images with a low sun angle where operator judgement is needed to accurately separate inter-tree shadows from shaded crowns.

4. Improved Tree Crown Extraction

Locating individual crowns is perhaps the most exacting part of forest analysis. In this project phase, several of the test sites were imaged on a single flight line and were afflicted with the same problem, i.e. very poor crown definition resulting from a high solar elevation.

"Stem 8" is the worst example of this. In this site the digitized area, removed from the context of the original photograph was extremely difficult to interpret either by analyst or by computer. It was not clear if the area was all forest or partially brushland, or where the forest boundary occurred.

Preprocessing operations not used in previous work were eventually incorporated to alleviate the problem. Histogram equalization contrast stretching was used to accentuate the shadow areas. While stretching does not have an effect on level slicing it does often make an image more interpretable, and nonlinear stretching has considerable impact on subsequent spatial operations. While stretching facilitated crown extraction for some of the sites, unsatisfactory results were still obtained in forested areas containing large differences in tree reflectances caused by a species mix. The versatile box filter was again relied upon to solve the problem; this time being used as a local intensity normalizing operator. With a box size set to span about five trees, dividing the original image by the filter output produced an image where crown definition was largely unaffected by the average grey levels associated with individual trees, only by the difference between these grey levels and the levels of the nearby shadows.

From this point extracting crowns via convolving the processed image with a template was more effective. As fully described in the previous Phases, the image was reduced in resolution by factors of the square root of two to bracket image scales where the template would be effective. Computation of pixel values in the reduced images was done by area averaging. After convolving the images with the template the results are restored to original scale by pixel replication. In all processing selection of the most appropriately scaled image was done by interactive slicing the template output. The analyst adjusts slice thresholds separately for each scale while viewing the resultant crown map superimposed on the original image. Visual inspection appears to be a workable means of selecting the proper scale as it is readily apparent when the mapped crowns do not correspond well with individual trees.

The crown location process is then completed by shrinking the areas mapped as crowns to single points via "Golay Processing", and then logically combining those points with the corresponding filtered forest theme by performing a logical "AND" operation.

IV. RESULTS OF DIGITAL PROCESSING

Processing of each of the digitized areas followed a consistent philosophy, that is, to first categorize the scene by using grey level in combination with spatially extracted information selected to separate the scene's content, and then to analyze the forested area, extracting themes which map the canopy and themes marking individual tree locations. The actual processing techniques used varied

considerably with different sites. In this section, each of the test sites is reported with a brief description of site content, along with any difficulties encountered or any interesting processing techniques employed. Following each description is a series of figures which start with images generated from raw digital data and end with tree crown themes. Included are figures showing results from various processing steps which were judged critical or unique. Coverage of the first sites processed is the most extensive as with later descriptions an effort was made to omit duplication and concentrate on novel processing steps. In view of the large total number of figures, individual figures are not addressed in the text.

A. Stem 3 Processing Results

Processing of the Stem #3 test site proved to be a quite a difficult task, but solving it has resulted in an improved procedure. The area contains three different forest stands, large deciduous trees, small darker trees which may be conifers, and a mixed area where trees are generally darker and have poorly distinguished crowns. Crowns in general were not nearly as well defined as in previously analysed areas. The scene was so difficult that, after consistently producing unsatisfactory and discouraging results, it was difficult to tell which techniques were working at all. Finally a disc file was set up to provide easy access and simultaneous viewing of texture operator outputs, and crown template outputs at a wide range of preprocessed scales. This facilitated retrieving the various derived images and assessing their usefulness for each processing task.

Difficulties started with categorizing the vegetation in the image. Without the theme filter this probably would have been impossible. Eventually density slicing was used to extract four very noisy classes. A barren class and a deep shadow class were both easily extracted by slicing grey levels, along with a very poor class which favored the small darker trees. The deciduous forest area was not directly extractable, so a general "bright foliage" class was used which included large tree crowns combined with grasses. The areas remaining were then grouped into a residual "unclassifiable" theme. Grasslands were separated from forest on the basis of texture as outlined in the previous project phases. To produce the required textural image the five pixel max-min textural operator was applied and the results smoothed with a 25 by 25 box filter. The classes were partitioned from the two dimensional space defined by grey level and smoothed texture.

Given these themes, inaccurate as they were, the theme filtering sequence used as fairly straight forward. First the unclassifiable theme, comprised primarily of mixed pixels covering both forest foliage and small shadows was resolved on a spatial basis by using an 11 by 11 filter. These pixels were allowed to go into only the two forest classes. The second step was to spatially resolve the deep shadow areas by an identical procedure. As a final filter step, general smoothing was applied to clean up the very noisy classification. Several minor errors, mainly associated with shadows, remain in the final themes but could be removed by interactive editing.

1

Locating the individual crowns was no less of a task. This scene had poorer crown definition than any scene previously analyzed. This was probably due to a high solar elevation angle at the time of image acquisition. The crown template was applied at many scales within remarkable results, the problem being that shadow areas between crowns were not dark enough to be sensed by the template. This situation was ultimately made workable by performing a histogram equalization contrast stretch on the data prior to application of the template. This histogram sample was taken from the forested area and being an "equal area" stretch, forced a substantial fraction of the forest area into low grey levels accentuating the shadows. Among the scales tested the best results were achieved when the working scale was reduced by the square root of two. The darker forest class contained trees too small to work with so no crowns were located.

The forest canopy theme, the last of the important tree themes, was derived by slicing all shadows out of the filtered forest themes.

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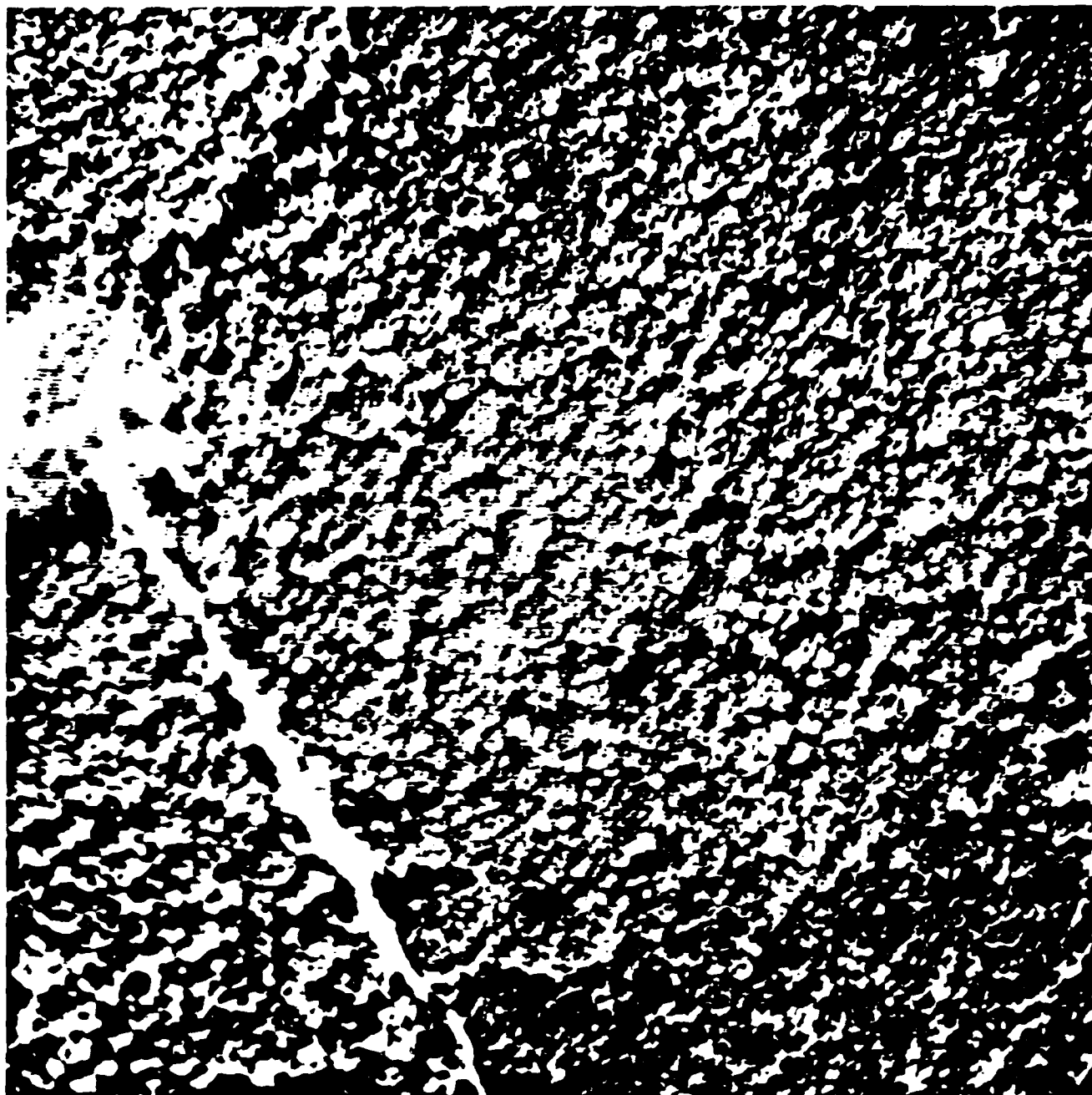


FIGURE 8

STEM 3 - Raw Data

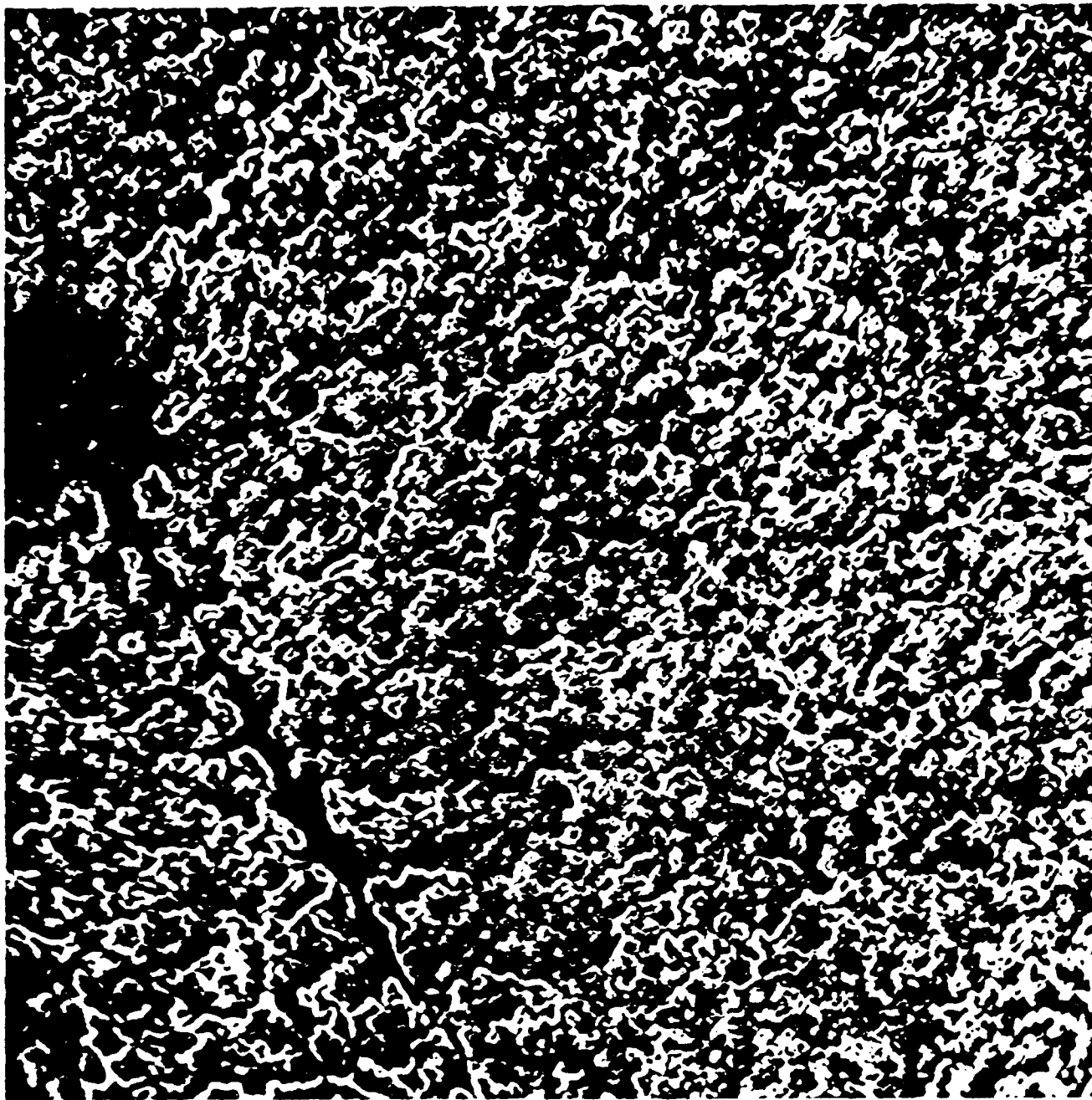


FIGURE 9

STEM 3 - Texture From 5 Pixel Operator

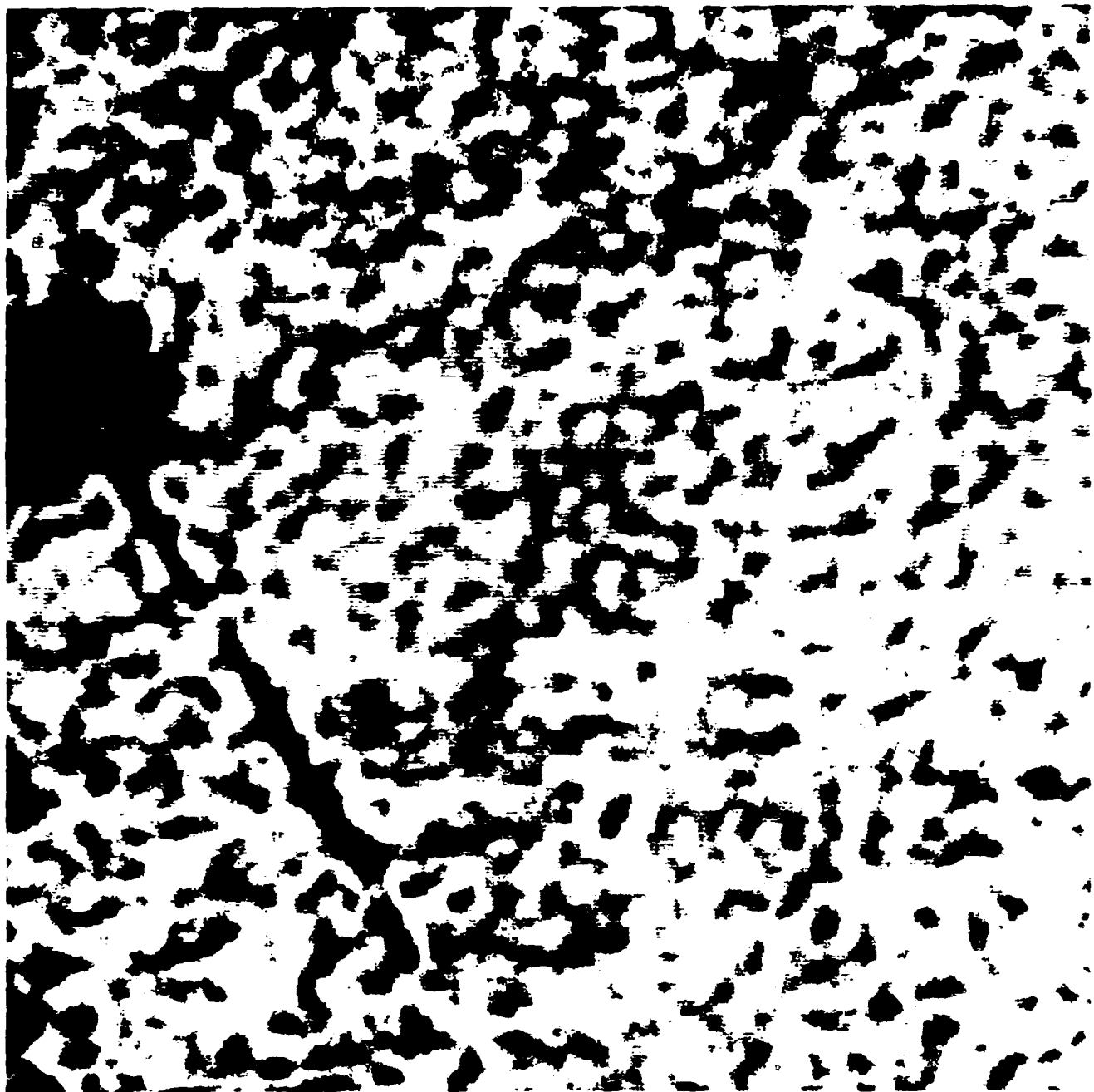


FIGURE 10

STEM 3 - 11 x 11 Pixel Smoothed Texture

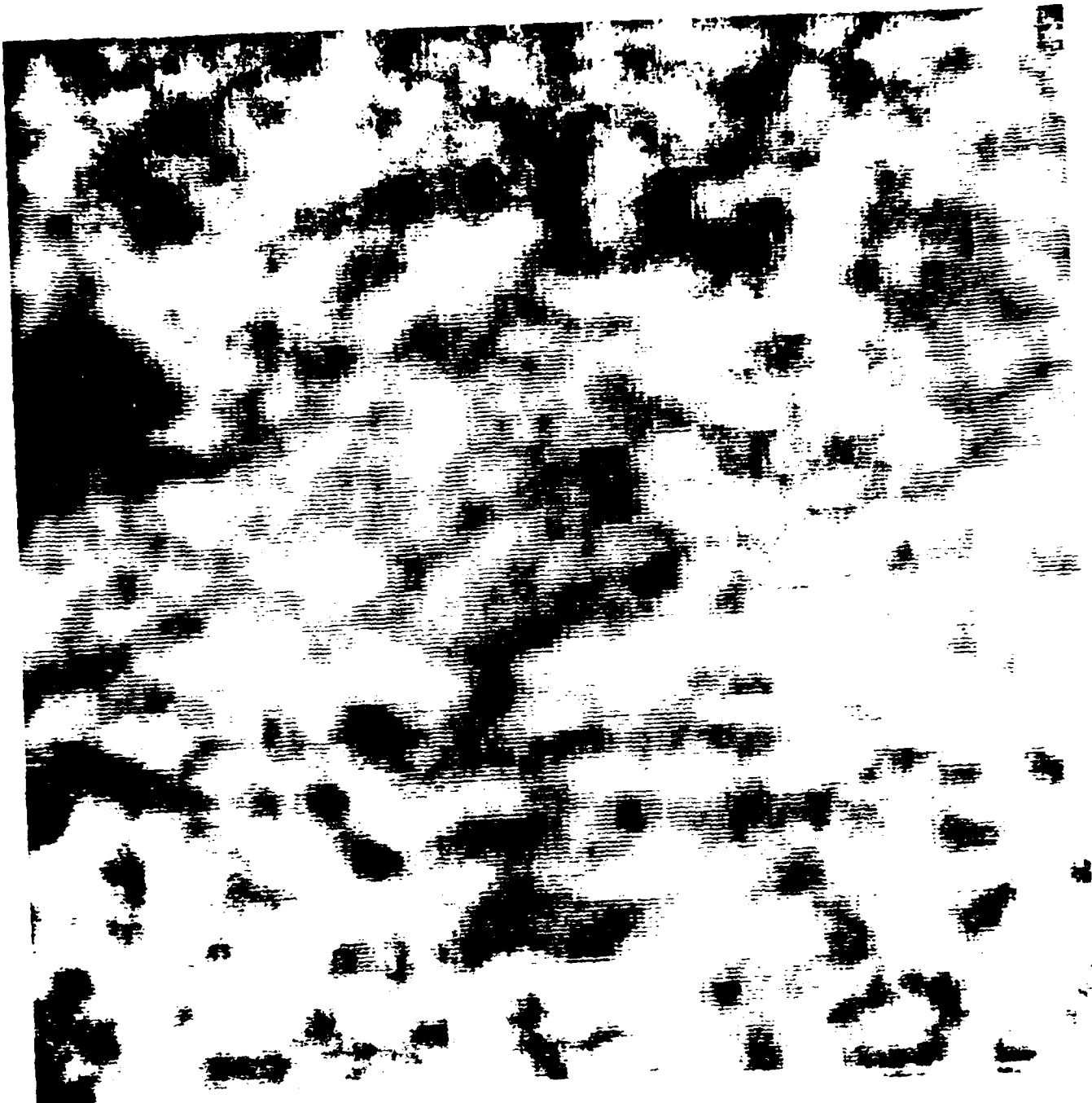
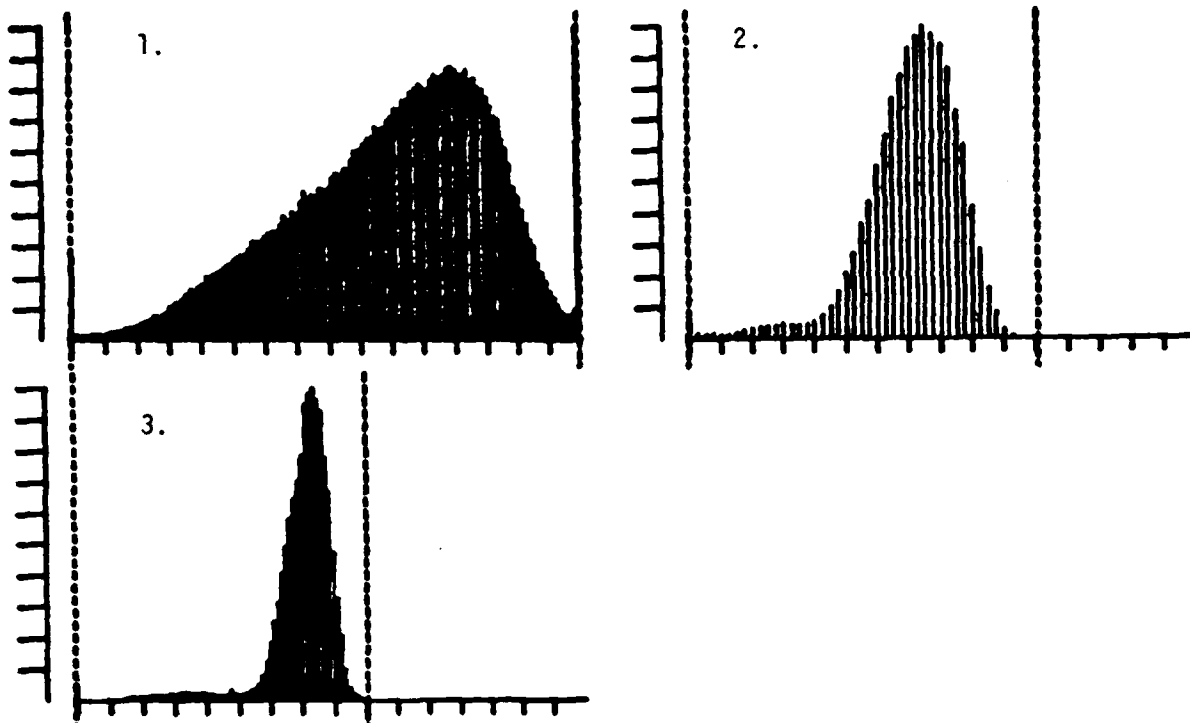


FIGURE 11

STEM 3 - 21 x 21 Pixel Smoothed Texture



TRAINING SUMMARY 25-MAR-82 12:13:25+
 # LB UB DEL PEAK MEAN VAR +
 1 0 127 128 4874. 80.1 659.1 +
 2 0 88 89 19241. 56.5 156.8 +
 3 0 72 73 19570. 55.9 76.9 +
 TRAINING AREA=250690. PIXELS +
 ALARMED AREA=259586 PIXELS(99.0%) +
 TYPE CHS. (C)OMPARE, L(O)AD, E(X)IT

STEM 3 RAW DATA
 HALF RESOLUTION TEXTURE
 25X25 SMOOTHED TEXTURE

FIGURE 12

STEM 3 - Key Histograms

2-D PROJECTION:
CH1(Y) VS CH2(X)

BARREN
34.139 236.255
GRASS
27.83 174.234
L TREE
84.143 174.234
UNCLAS
32.143 142.172
S TREE
52.143 84.140
SHADOW
20.143 4.82
(L)EFT, (R)IGHT
(T)OP, (B)OTTOM
(D)RAW, L(O)AD

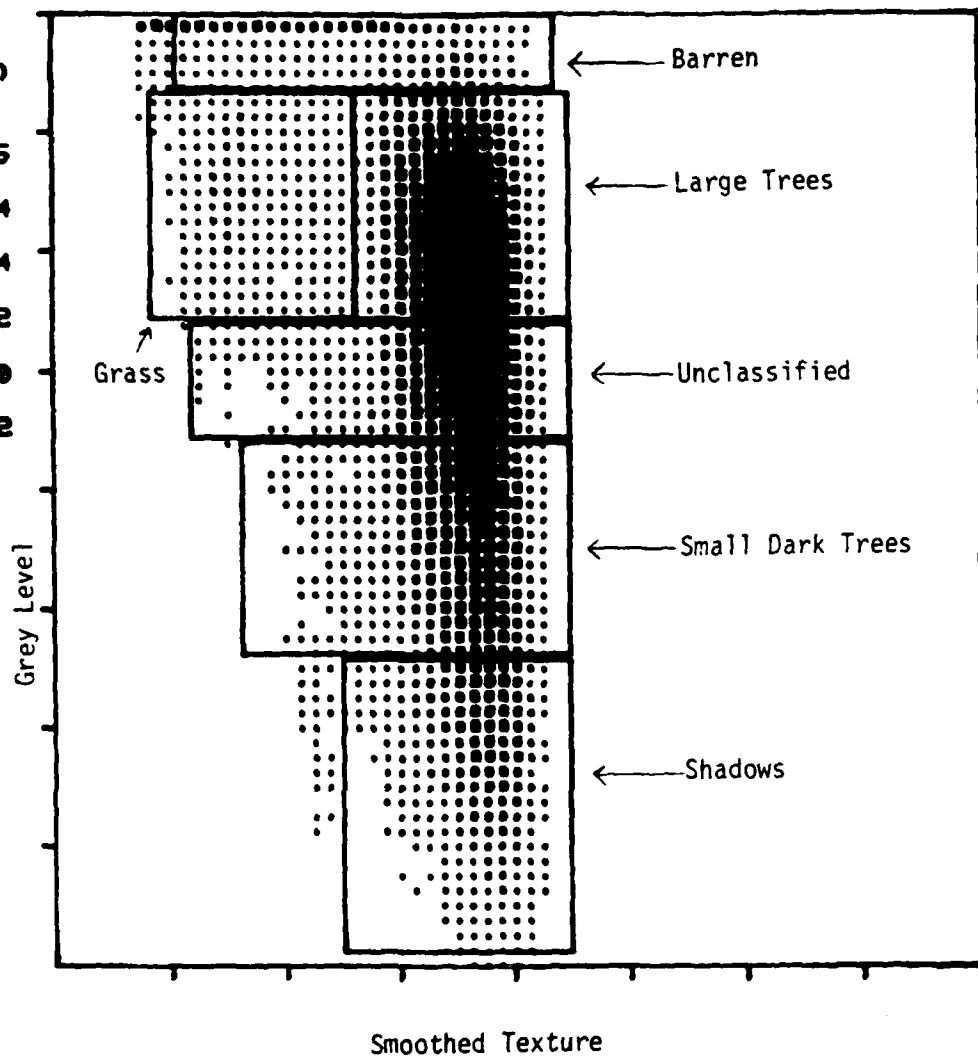


FIGURE 13

STEM 3 - Two dimensional histogram of raw data vs. texture.
Rectangles are the signatures of vegetation classes

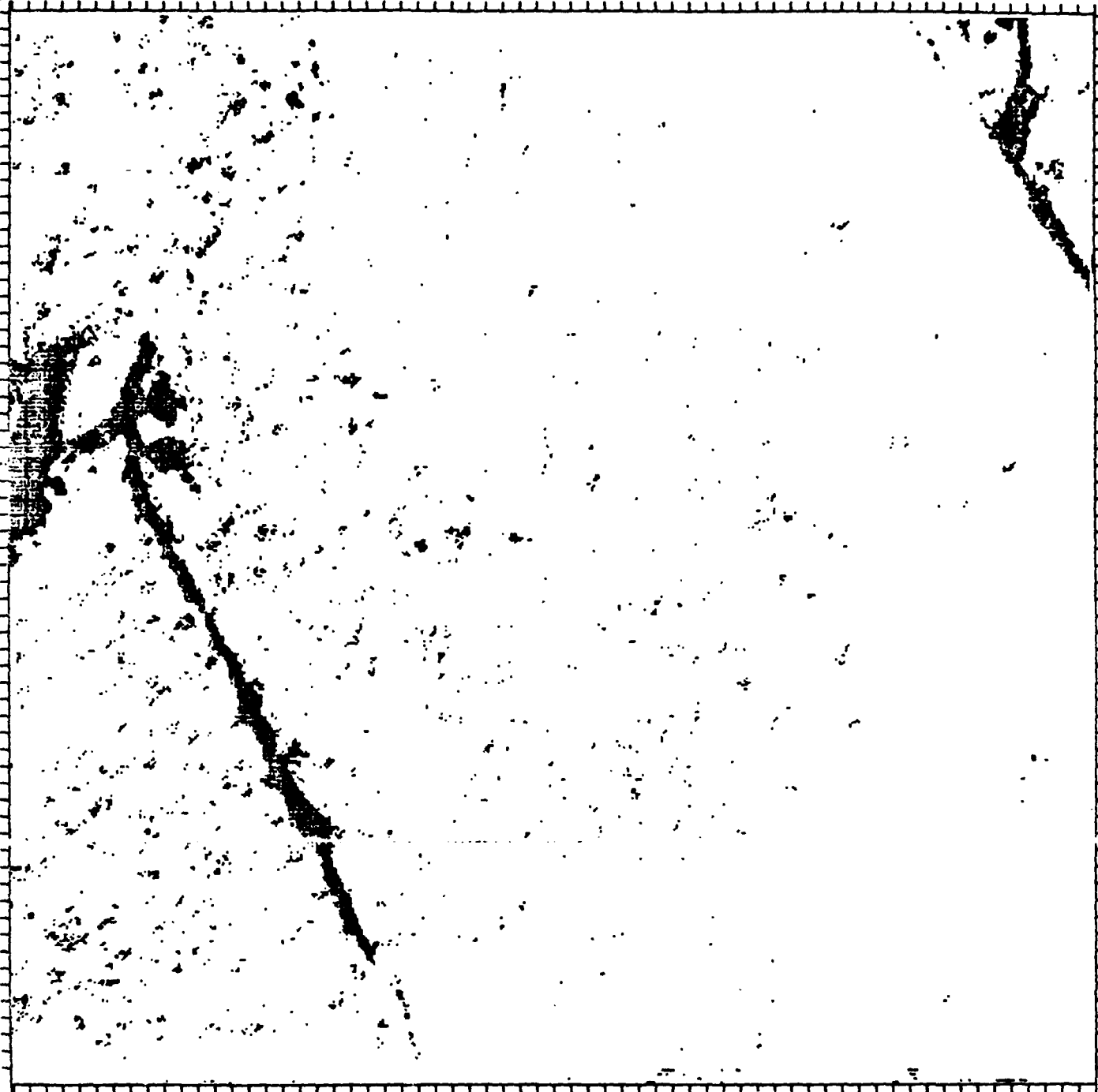


FIGURE 14

STEM 3 - Original Barren Class

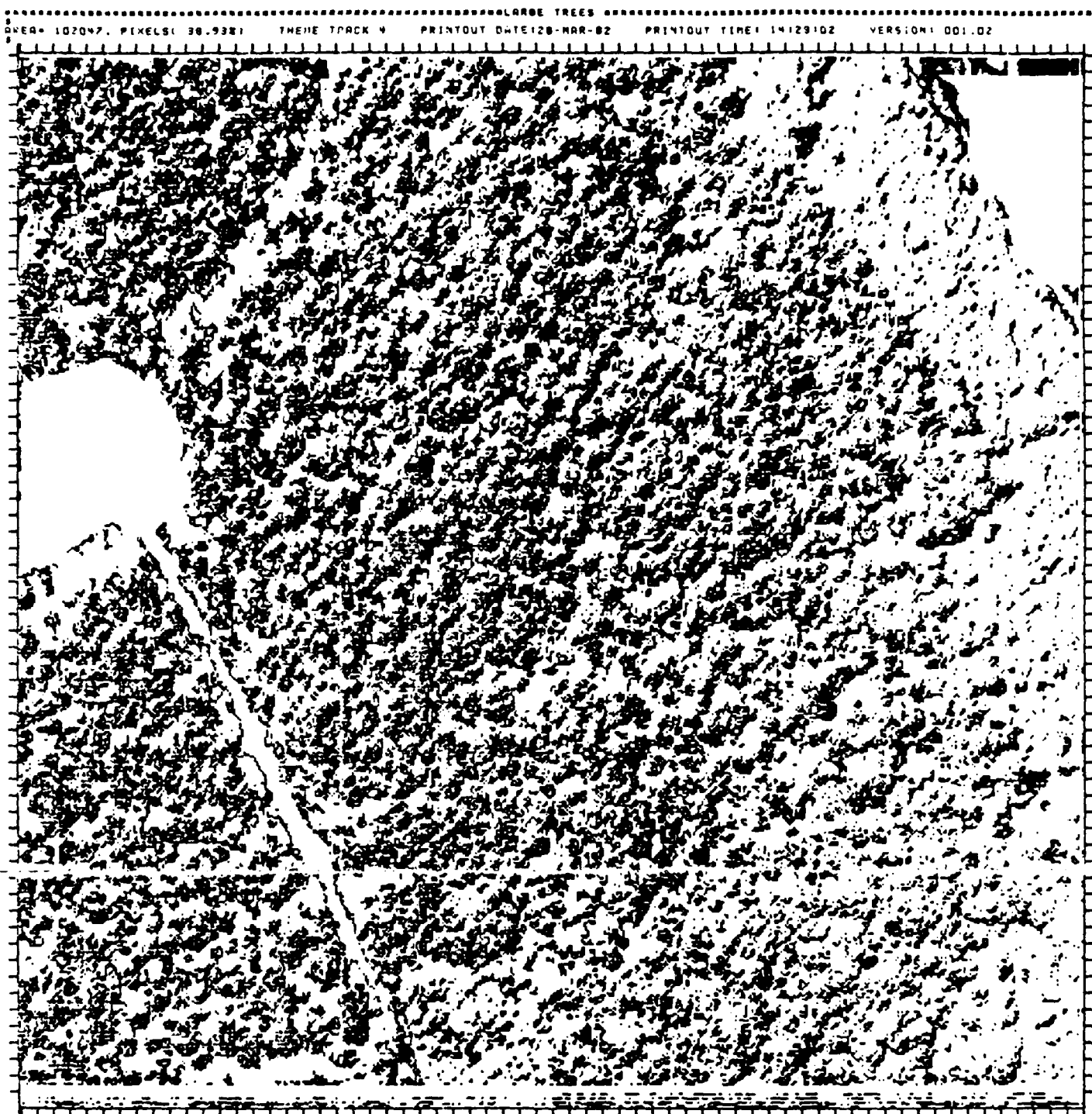


FIGURE 15

STEM 3 - Original Forest Class

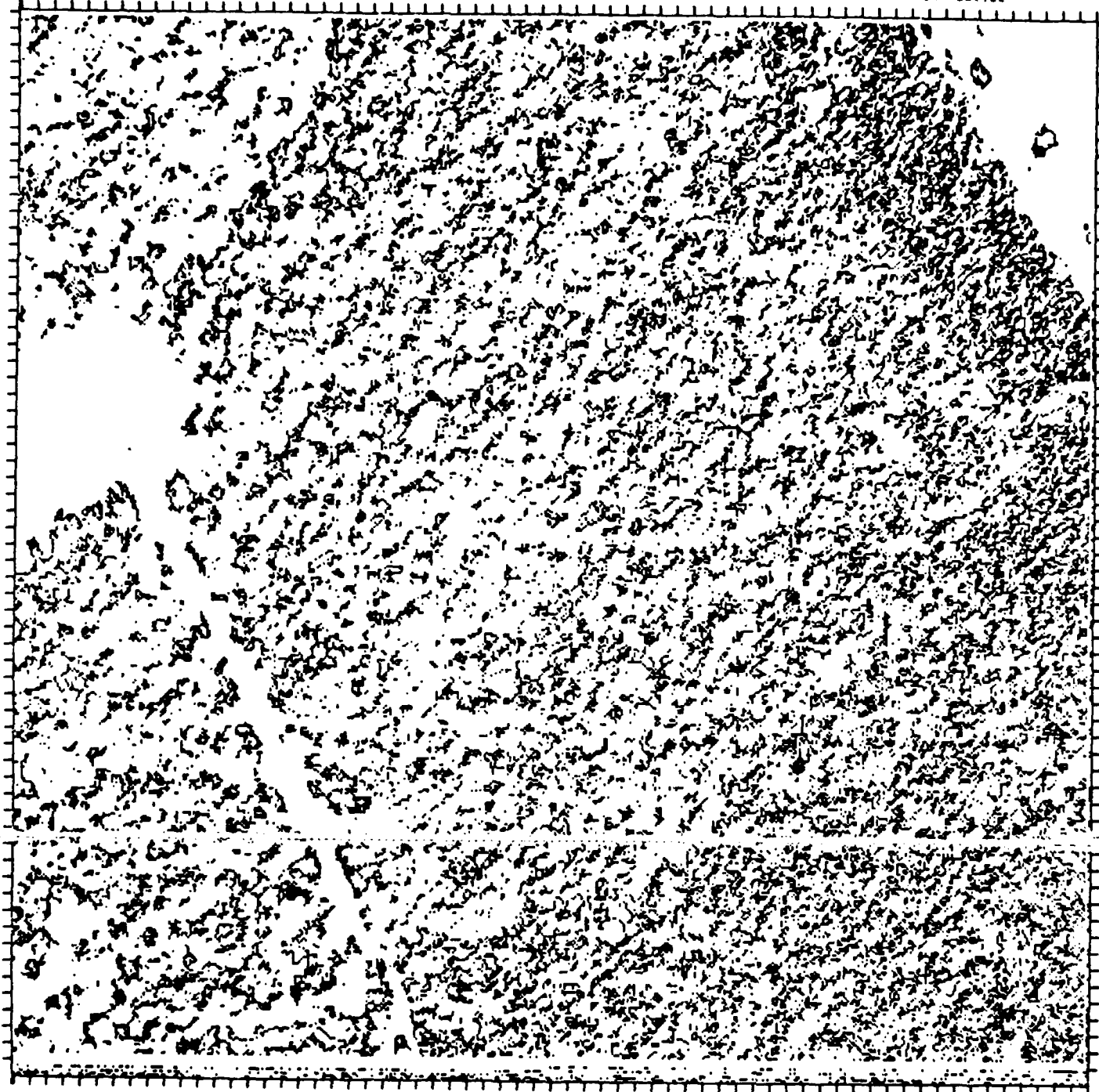


FIGURE 16
STEM 3 - Original Dark Tree Class

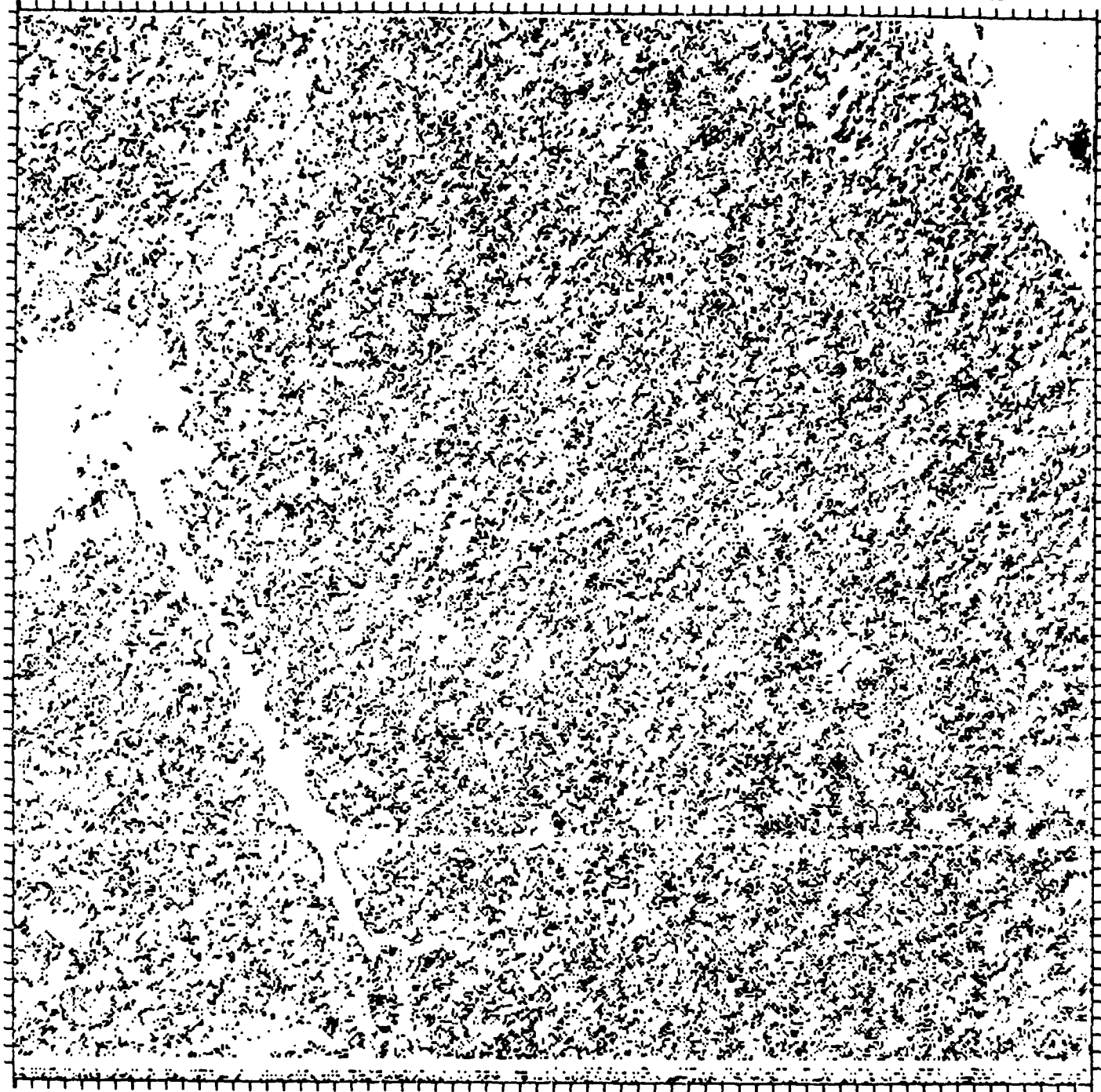


FIGURE 17

STEM 3 - Unclassified Pixels

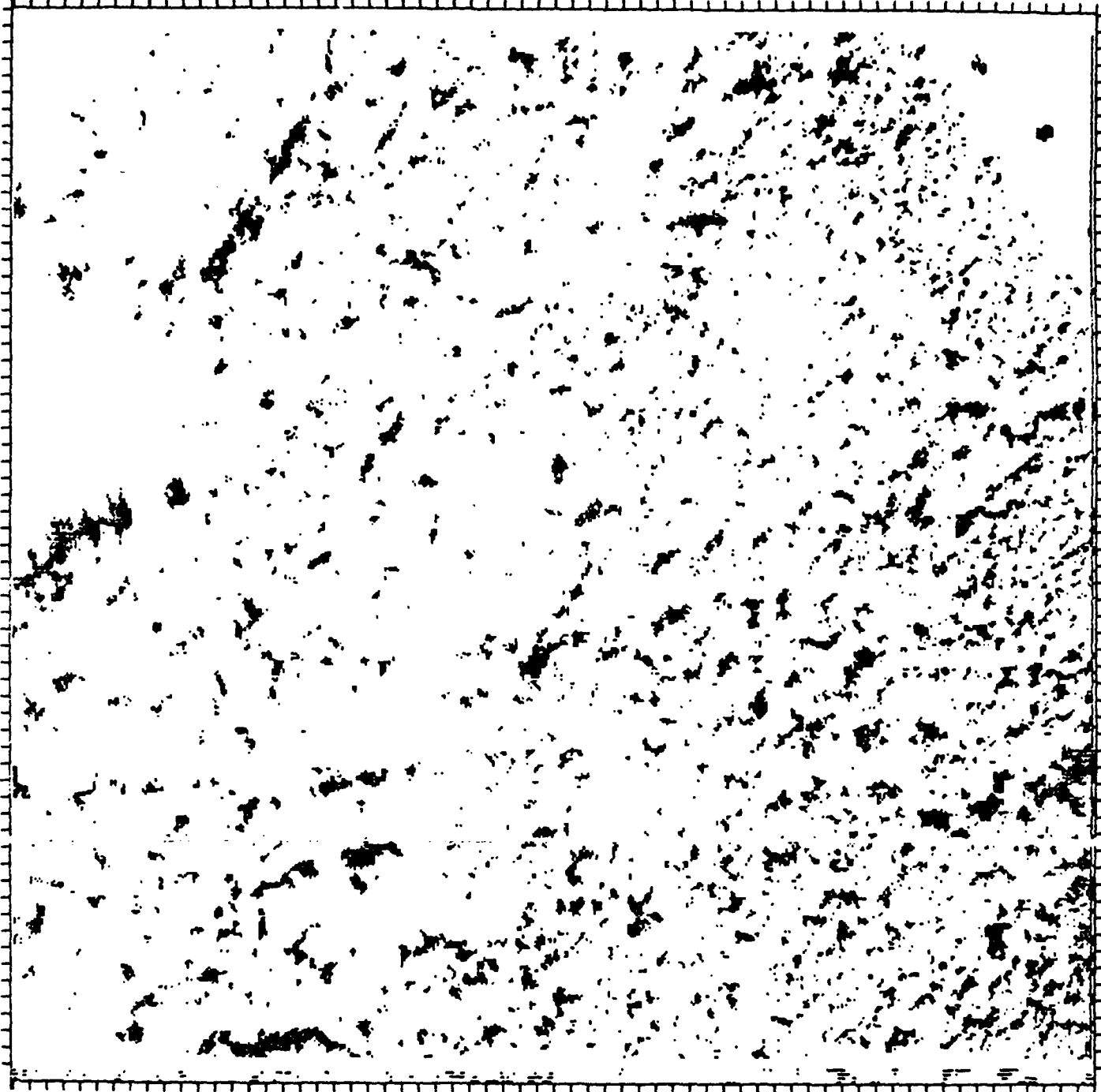


FIGURE 18

STEM 3 - Tree Shadows

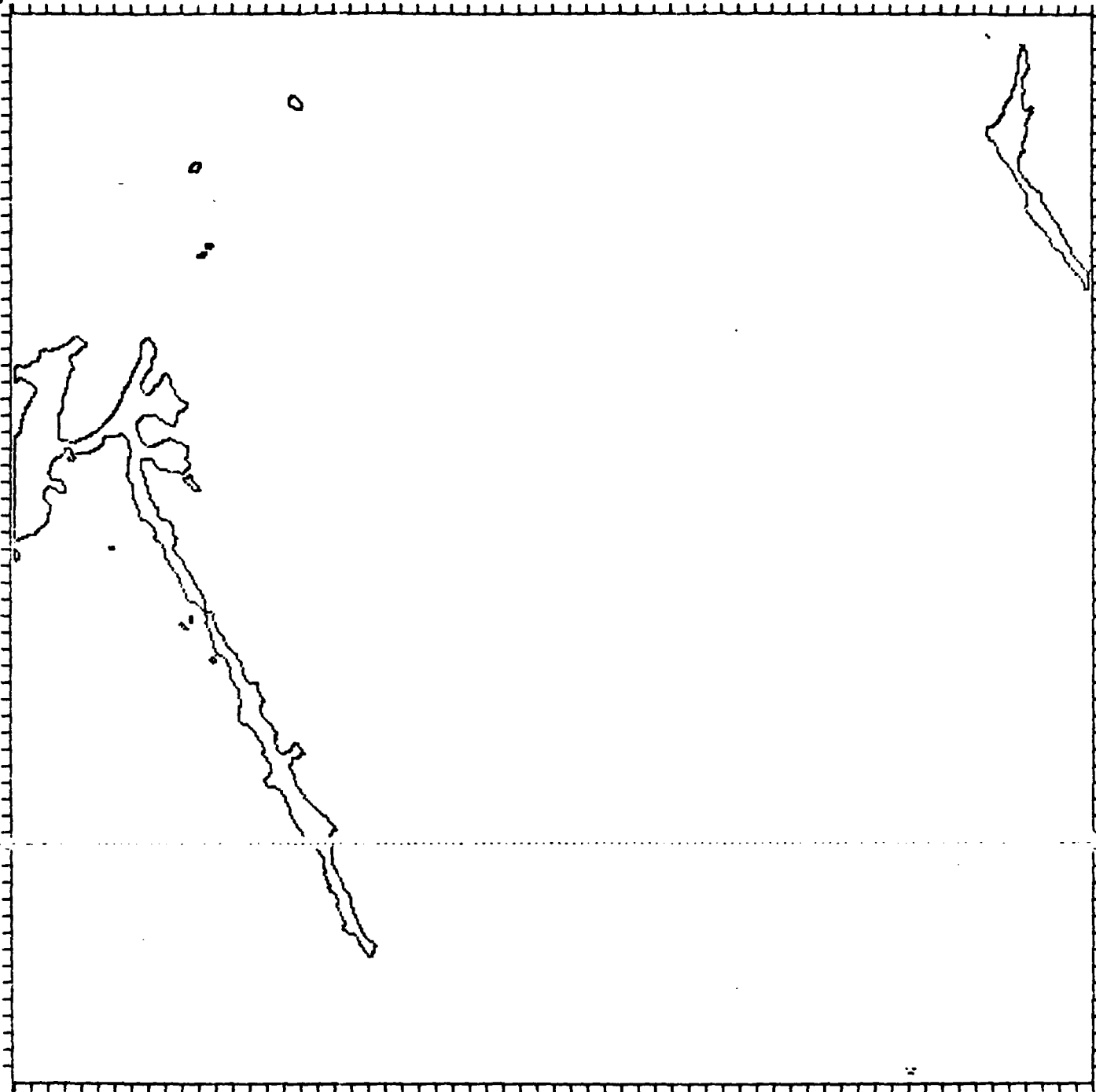


FIGURE 19

STEM 3 - Filtered Barren Class

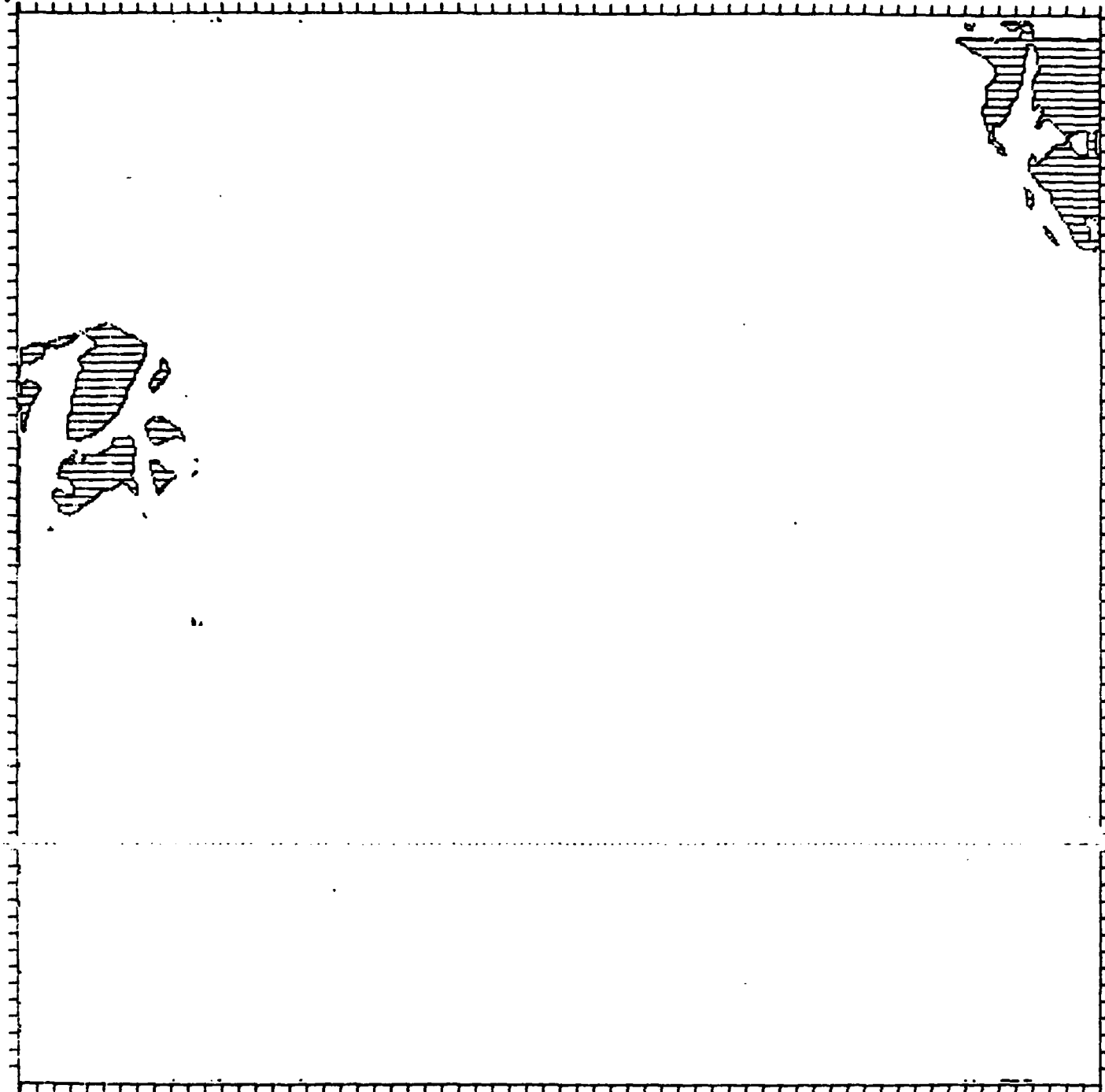


FIGURE 20
STEM 3 - Filtered Grassland Class

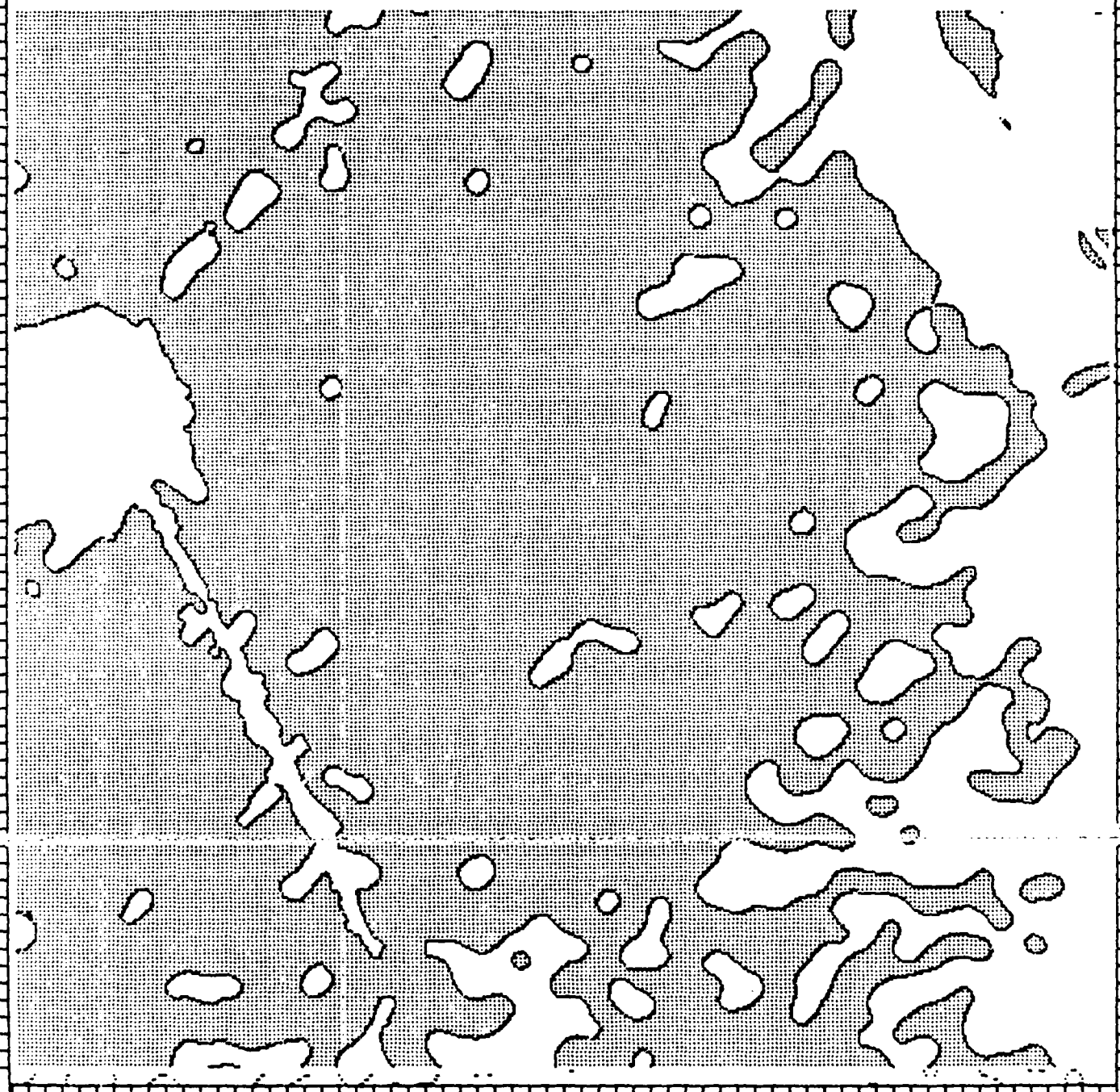


FIGURE 21
STEM 3 - Filtered Forest Class

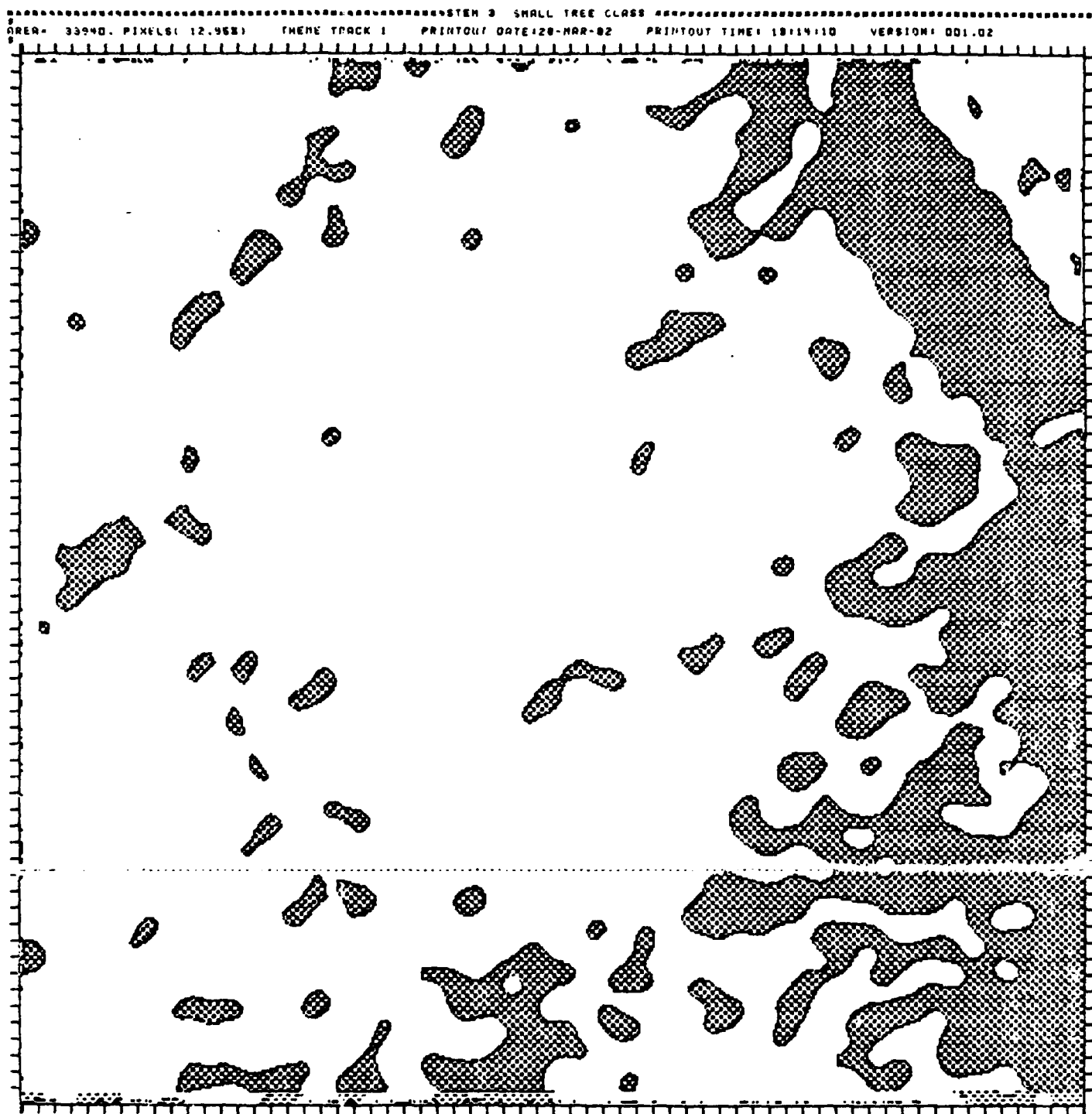


FIGURE 22

STEM 3 - Filtered Dark Tree Class

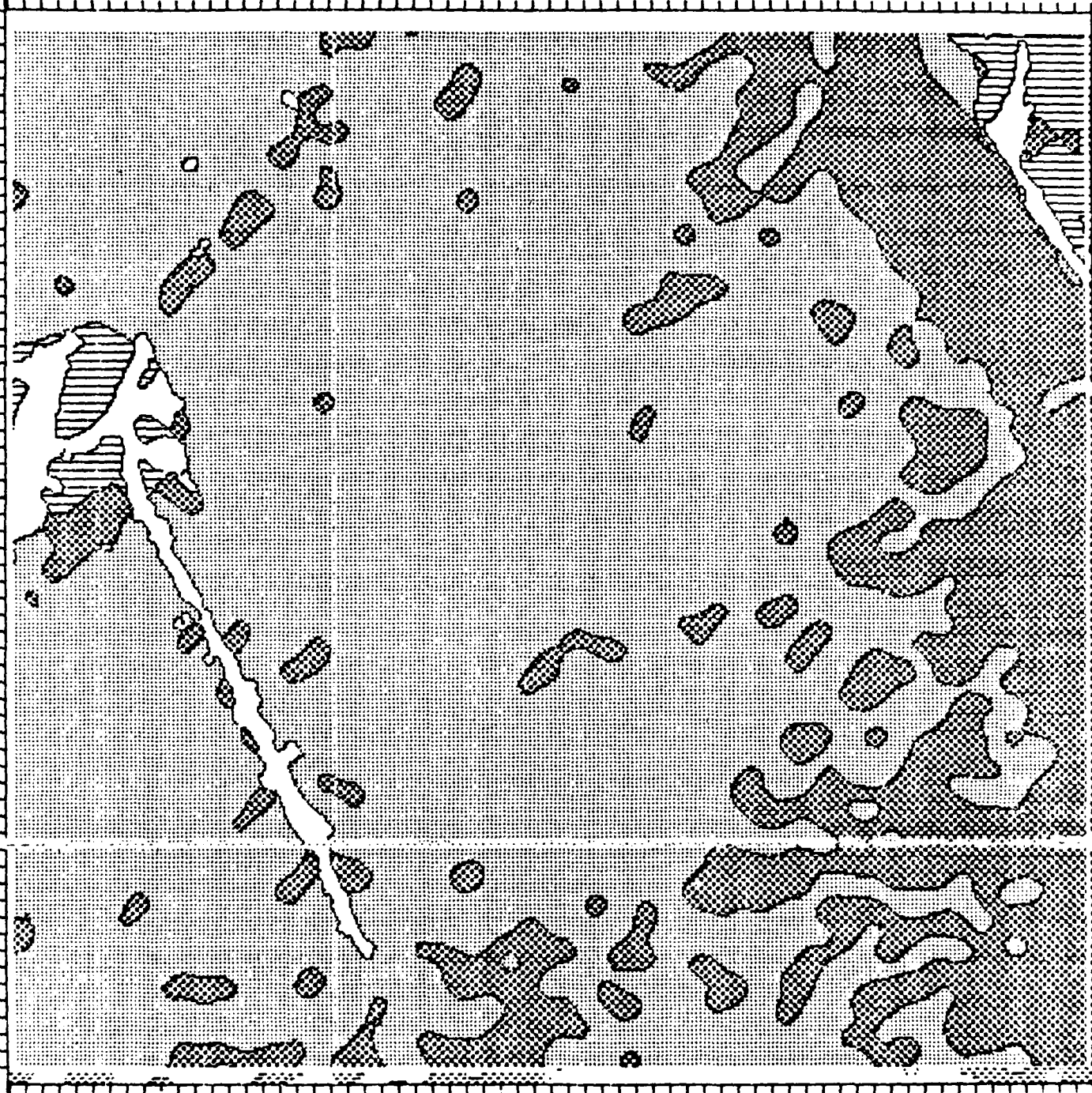


FIGURE 23

STEM 3 - Filtered Vegetation Classes

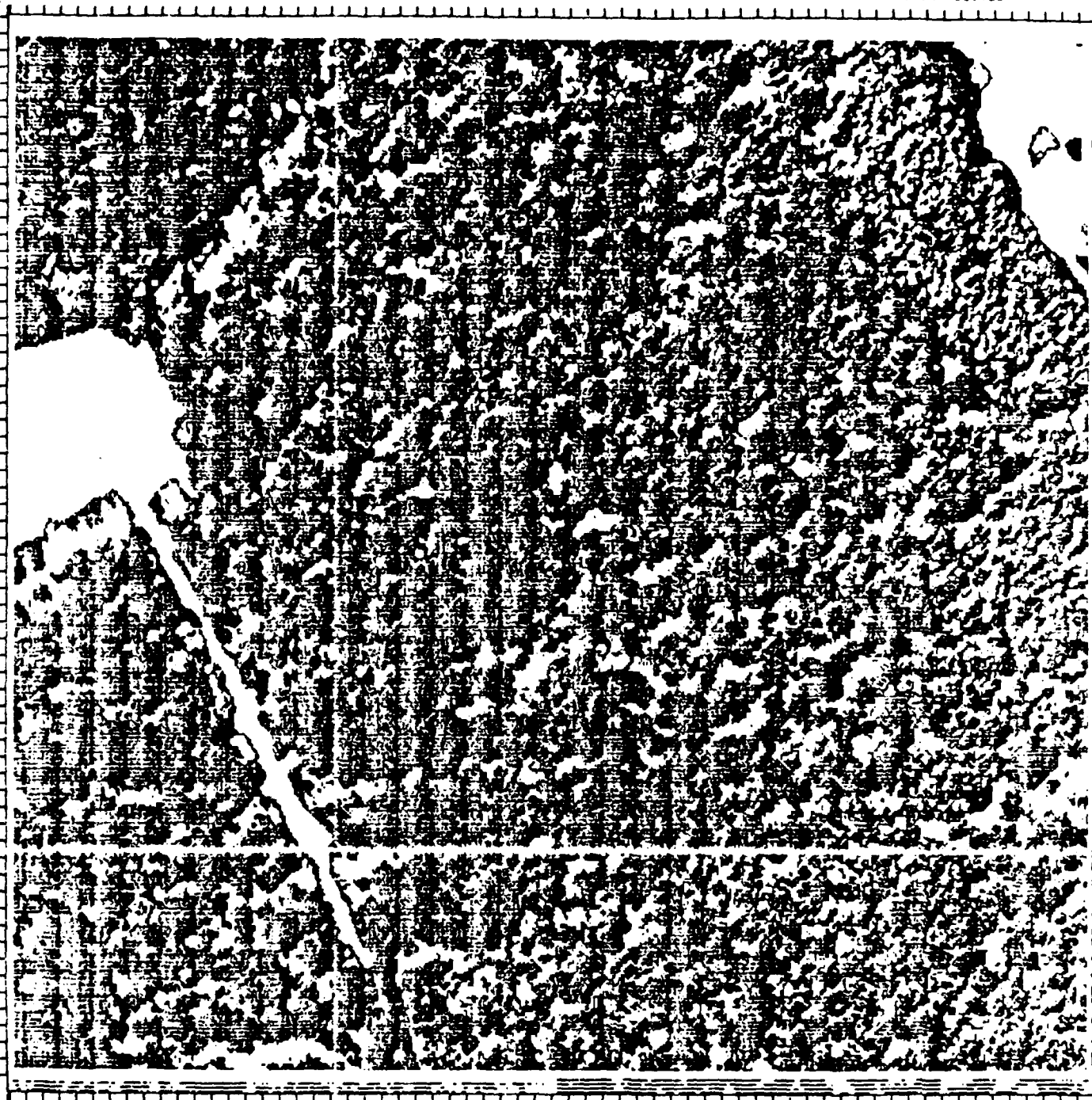


FIGURE 24

STEM 3 - Forest Canopy Theme Generated By Removing Shadows From
The Filtered Forest Theme

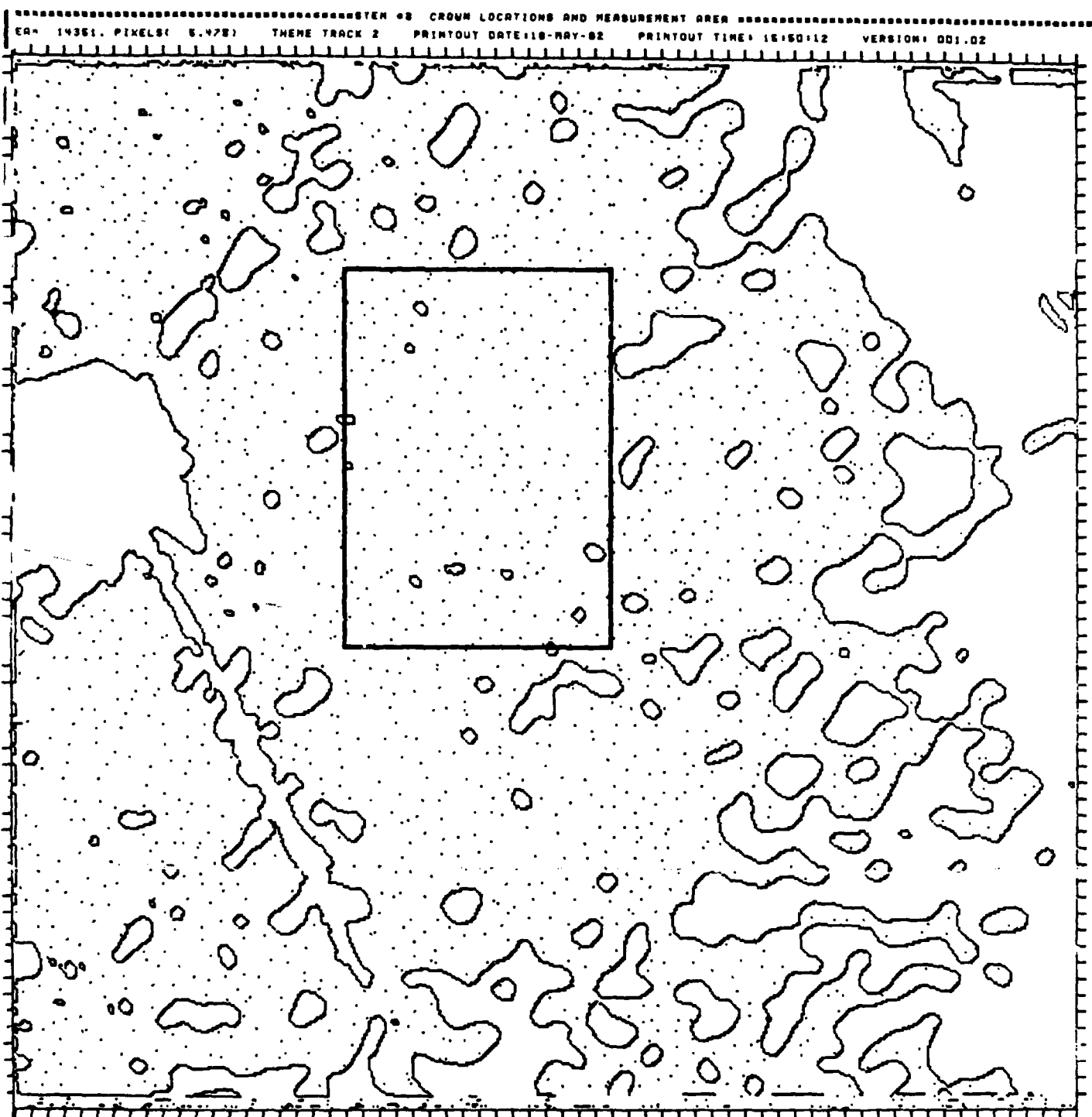


FIGURE 25
Stem #3 - Crown Location Theme
Stem Density 98 stems/ha
in boxed area

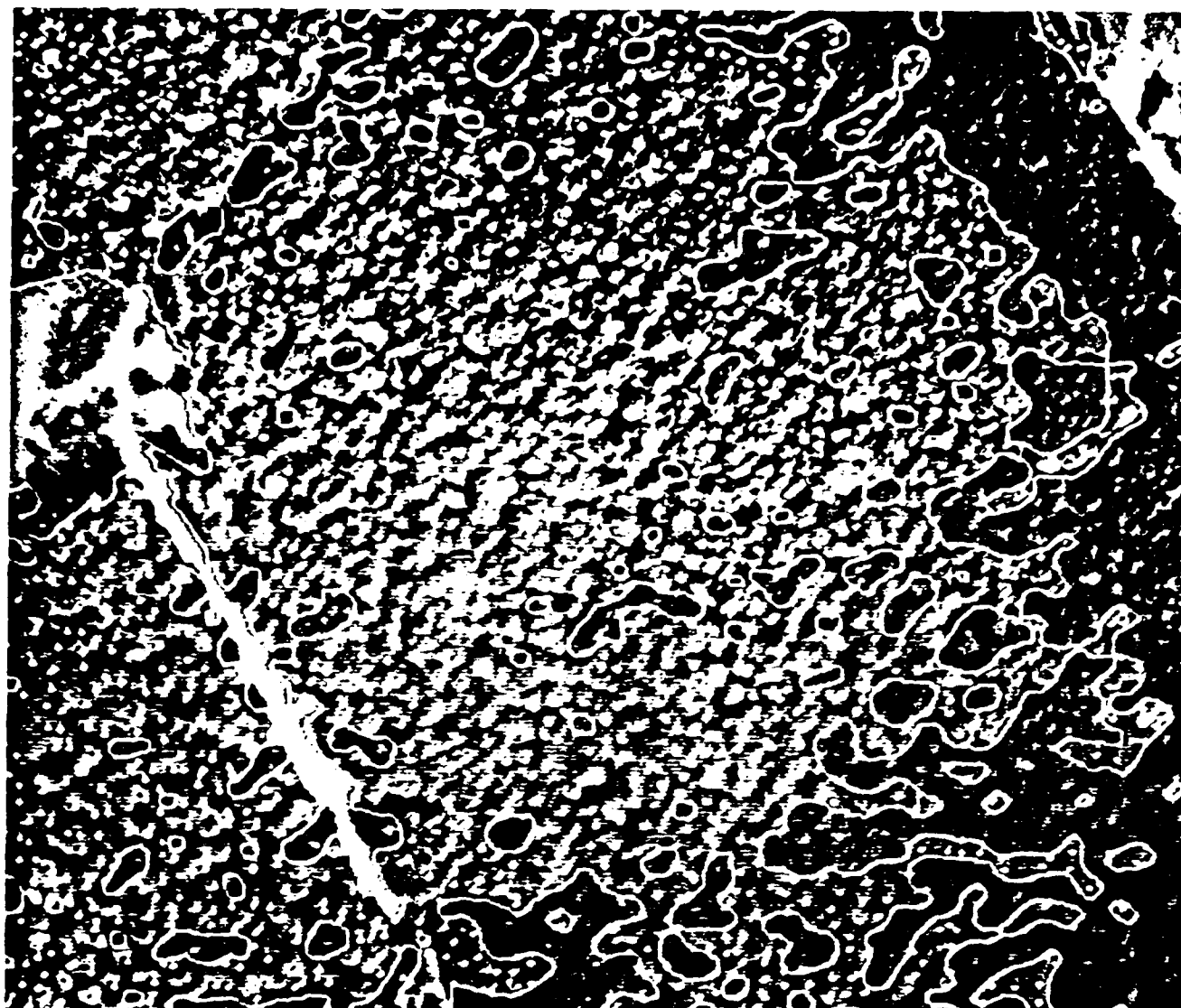


FIGURE 26

STEM 3

CROWN LOCATIONS SUPERIMPOSED ON TREES

B. Stem 7 Processing Results

This area was digitized from the color Ektachrome transparency covering the Fort Belvoir hunting reserve. Processing was relatively easy when compared to other test areas taken from the same transparency, probably because the predominant trees were mature deciduous and on the image, crown definition was fair to good. A second class of trees were notably darker in tone, and were dominant in one section of the digitized area. The same dark species was lightly scattered throughout the remainder of the area.

Classification of the image was based on image density and a 31 x 31 smoothing of the five pixel texture operator output, and was performed easily in the density vs. texture data space. Feature content of the site was such that several data clusters were well defined. There were a total of six classes extracted. Four were associated with vegetation and included, forest, dark forest, barren and grass. The remaining two were nuisance classes, shadows and conflict between barren and grass. Filtering of classes followed the usual sequence of resolving nuisance classes spatially, and then low pass filtering the resulting classes to straighten boundaries.

To accentuate crown definition, a histogram equalization stretch was applied to the data prior to application of the crown template. No quantitative measurements were made, but it was felt this operation improved template operation.



FIGURE 27

STEM 7 - Raw Data



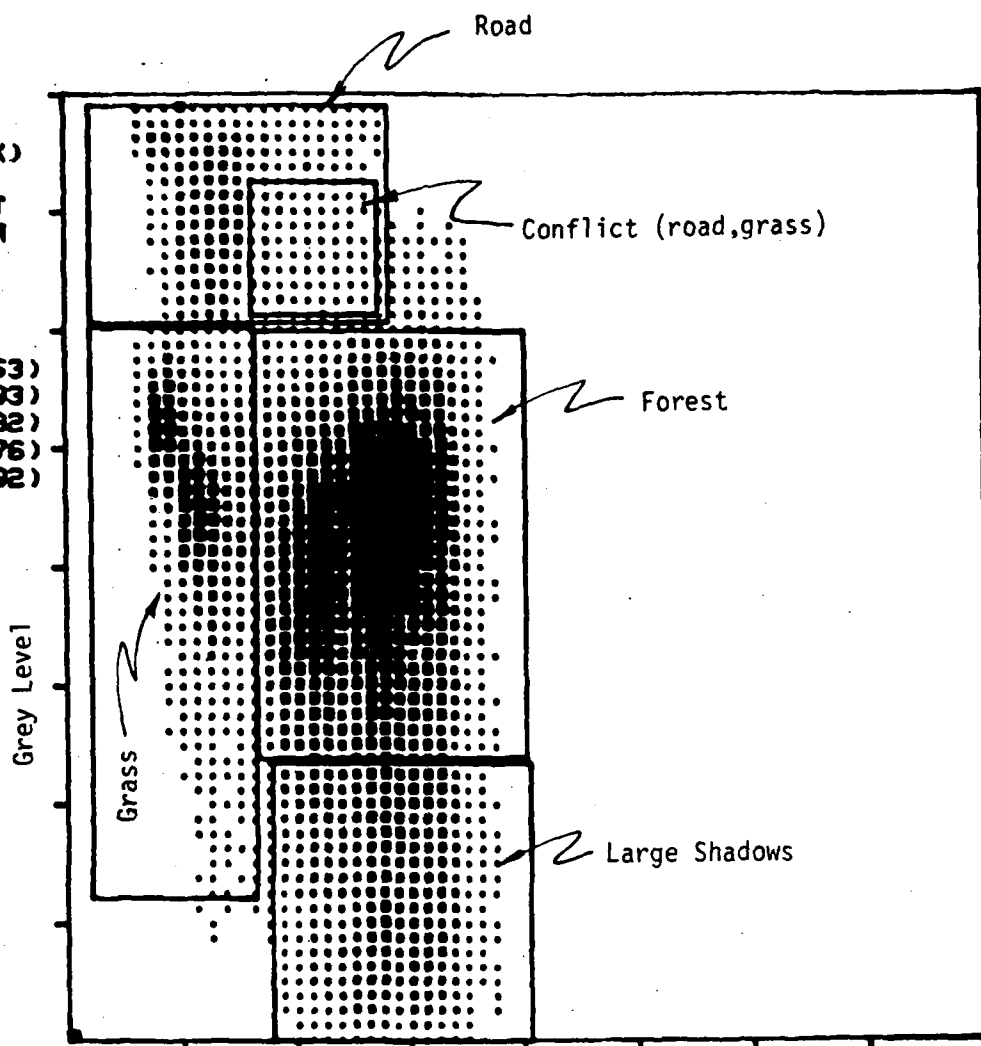
FIGURE 28

STEM 7 - 11 x 11 Pixel Smoothed Texture

2-D PROJECTION
CH1(Y) VS CH4(X)

(L)EFT. (R)IGHT
(T)OP. (B)OTTOM
(D)RAW. L(O)AD

(7- 91.194-253)
(7- 53. 39-193)
(52- 88.196-232)
(57-130. 0- 76)
(53-129. 77-192)



31 x 31 Pixel Texture

FIGURE 29

STEM 7 - Vegetation Class Signatures

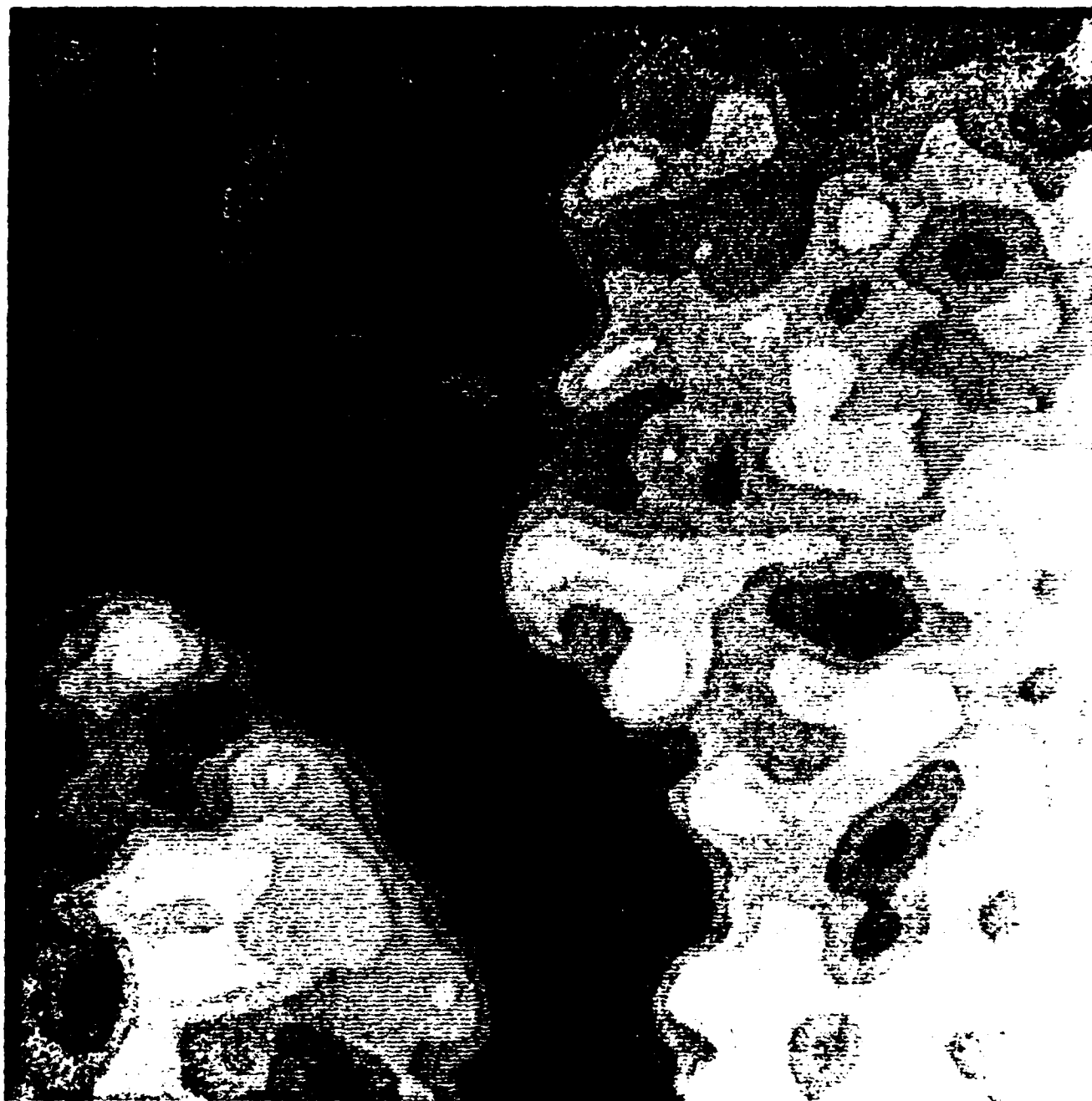
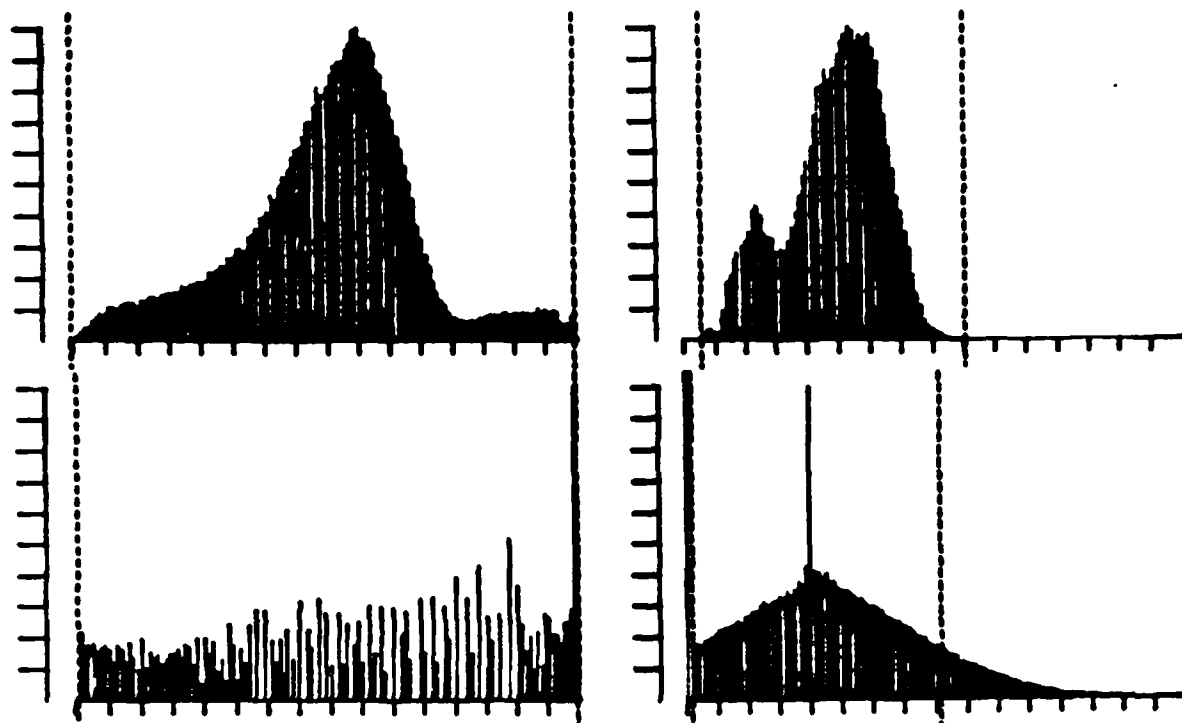


FIGURE 30

STEM 7 - 31 x 31 Pixel Smoothed Texture



TRAINING SUMMARY 17-APR-82 16:25:58+
 # LB US DEL PEAK MEAN VAR +
 1 0 127 128 5589 64.4 507.9 +
 2 5 72 68 7930 38.8 150.3 +
 3 1 127 127 11087 69.31555.1 +
 4 2 65 64 9443 33.2 258.3 +
 TRAINING AREA=226540. PIXELS +
 ALARMED AREA=135689 PIXELS(74.6%) +
 TYPE CHS. (C)OMPARE. L(O)AD. E(X)IT

STEM 7
 1. RAW DATA
 2. SMOOTHED TEXTURE
 3. HISTOGRAM STRETCH
 4. CROWN TEMPLATE OUTPUT

FIGURE 31

STEM 7 - Key Histograms

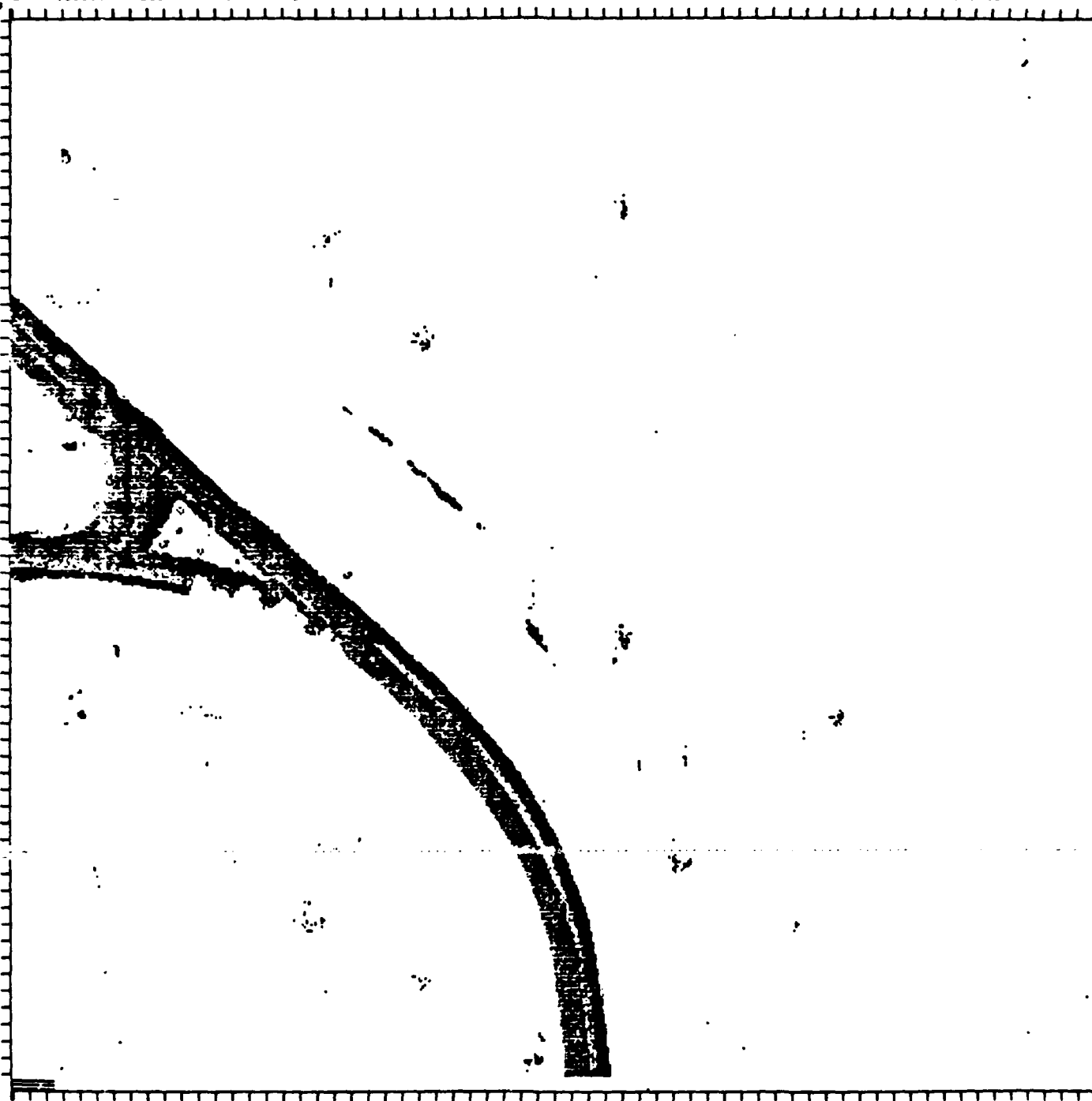


FIGURE 32

STEM 7 - Original Barren Class

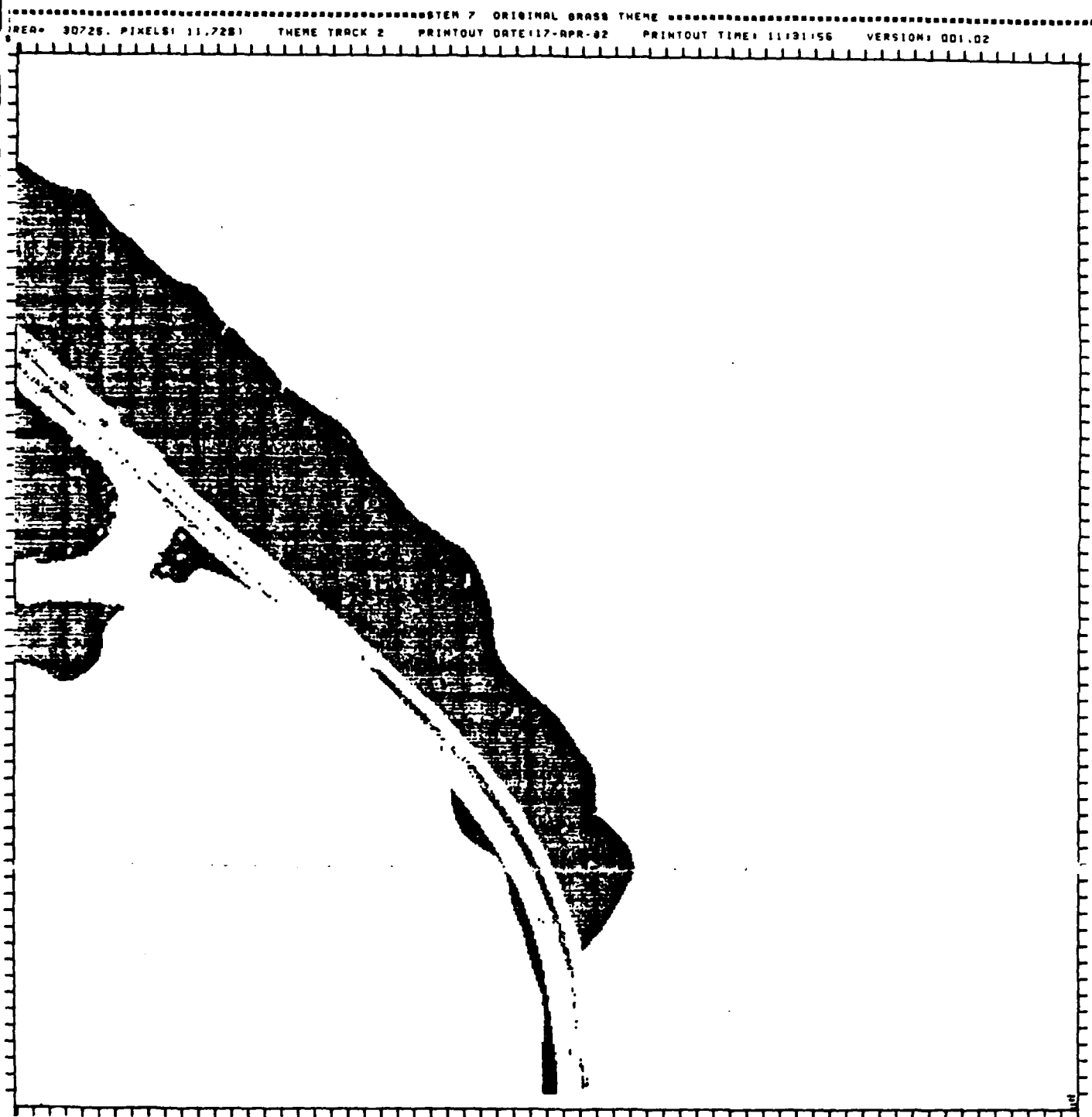


FIGURE 33

STEM 7 - Original Grassland Class

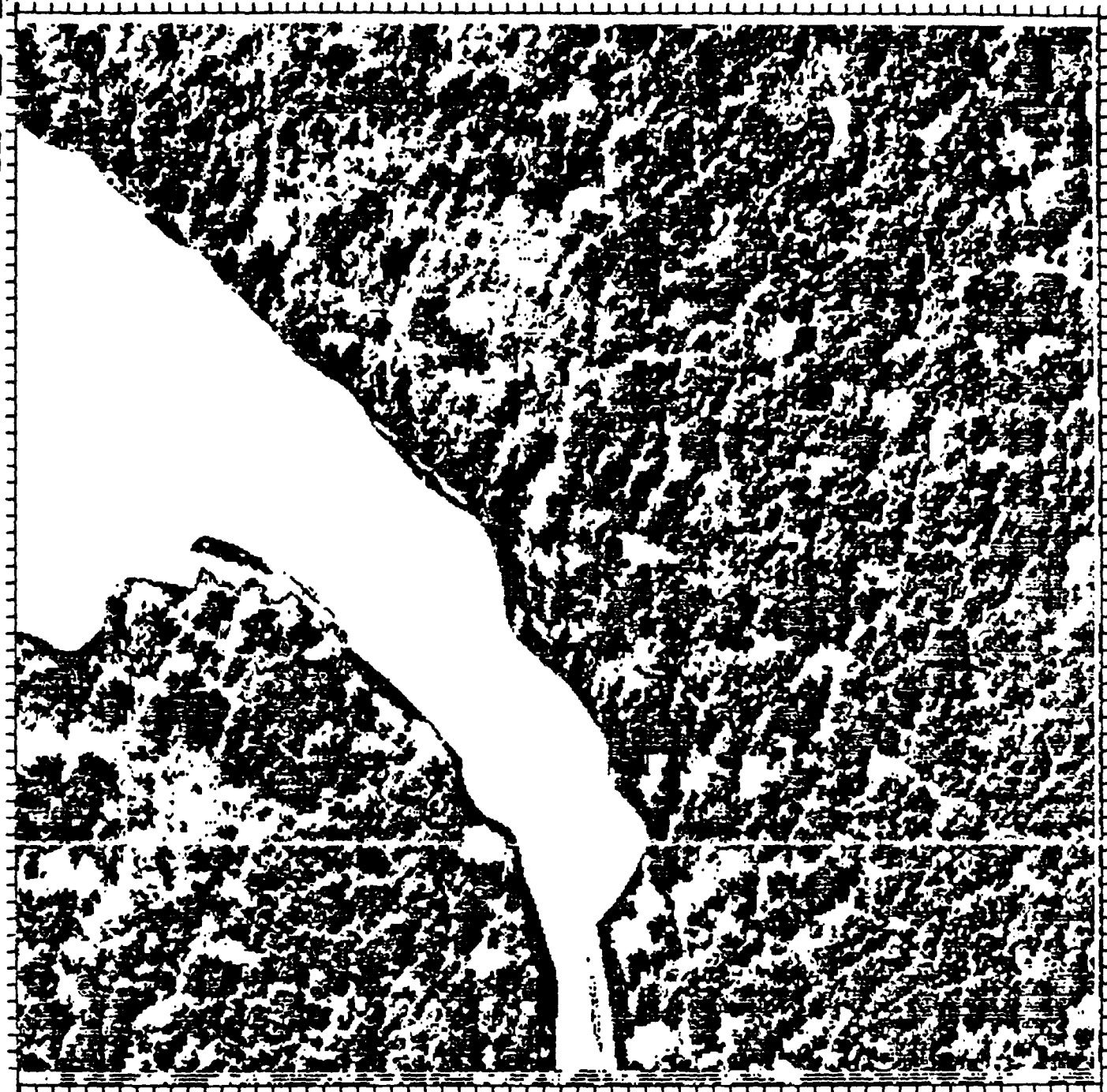


FIGURE 34
STEM 7 - Original Forest Class

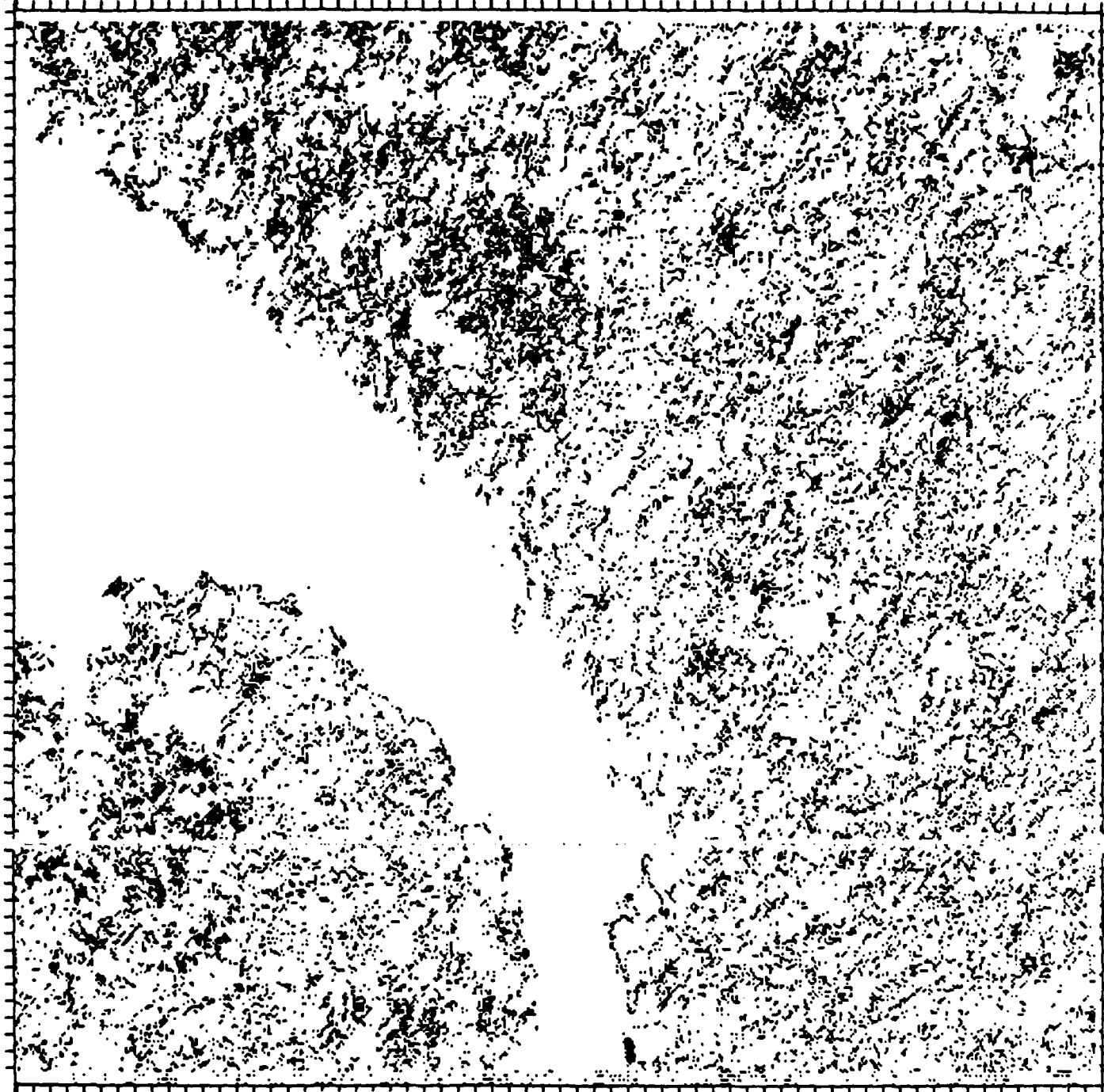


FIGURE 35
STEM 7 - Original Dark Tree Class

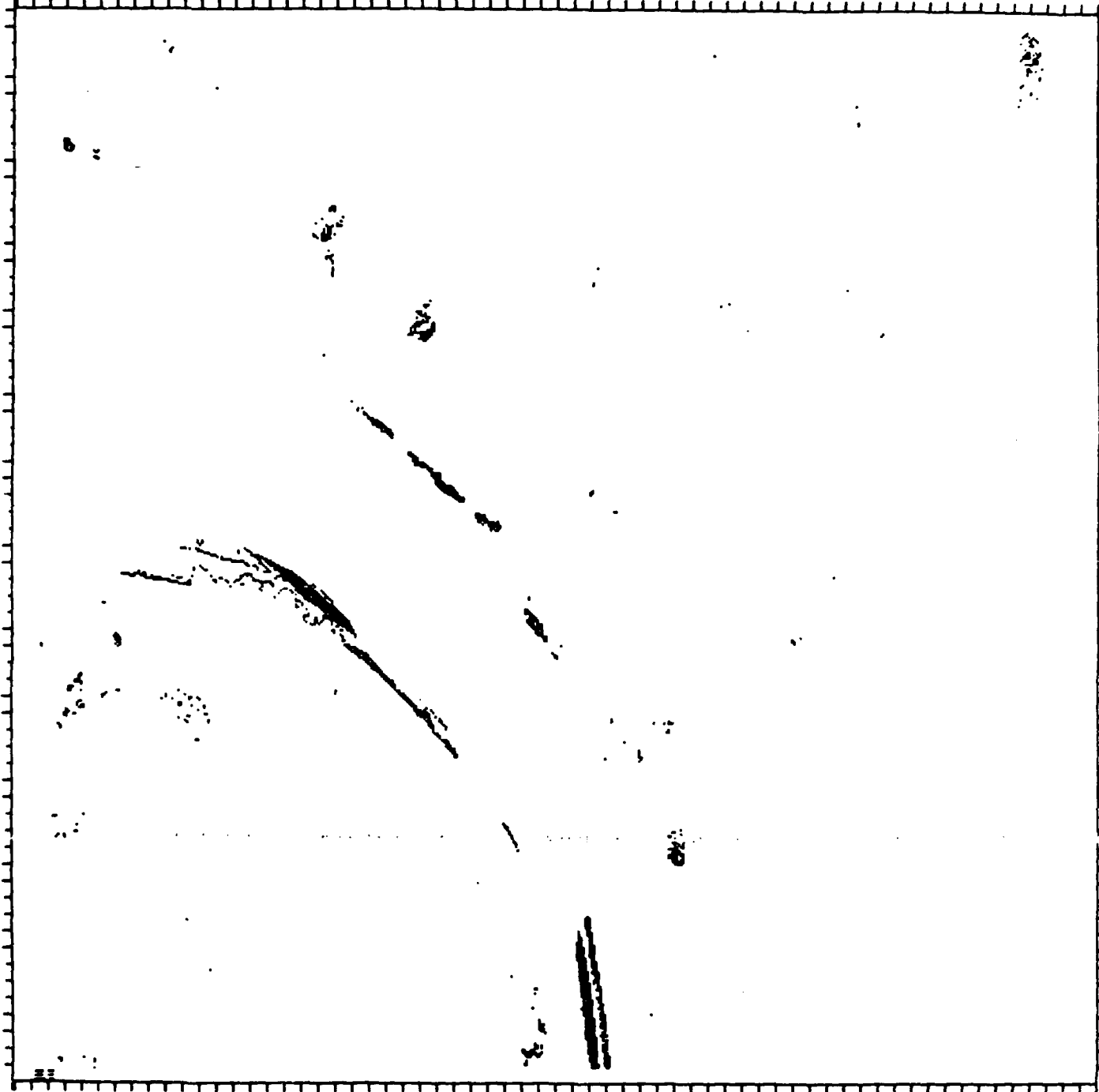


FIGURE 36
STEM 7 - Misclassified Pixels

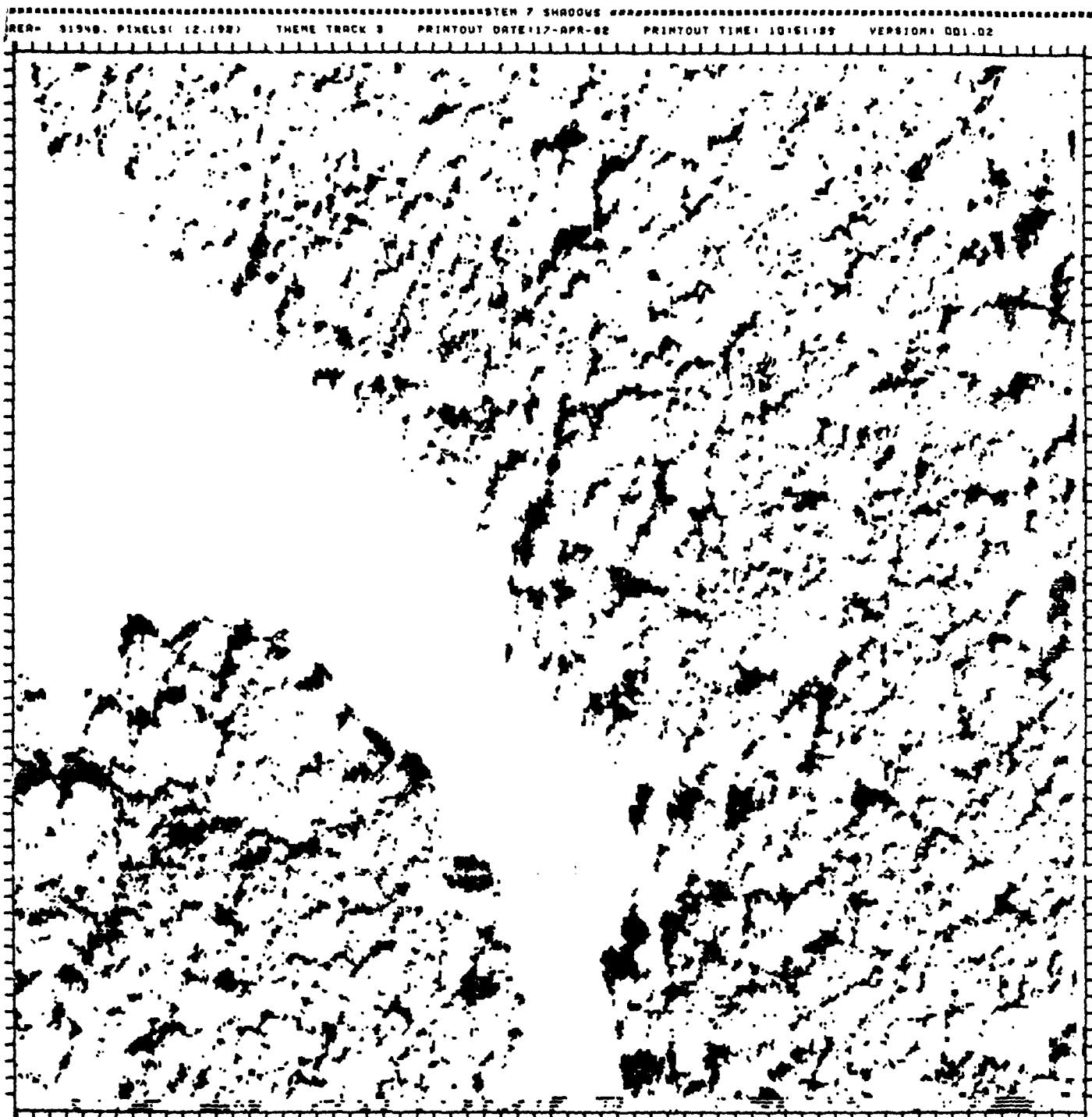


FIGURE 37

STEM 7 - Tree Shadows

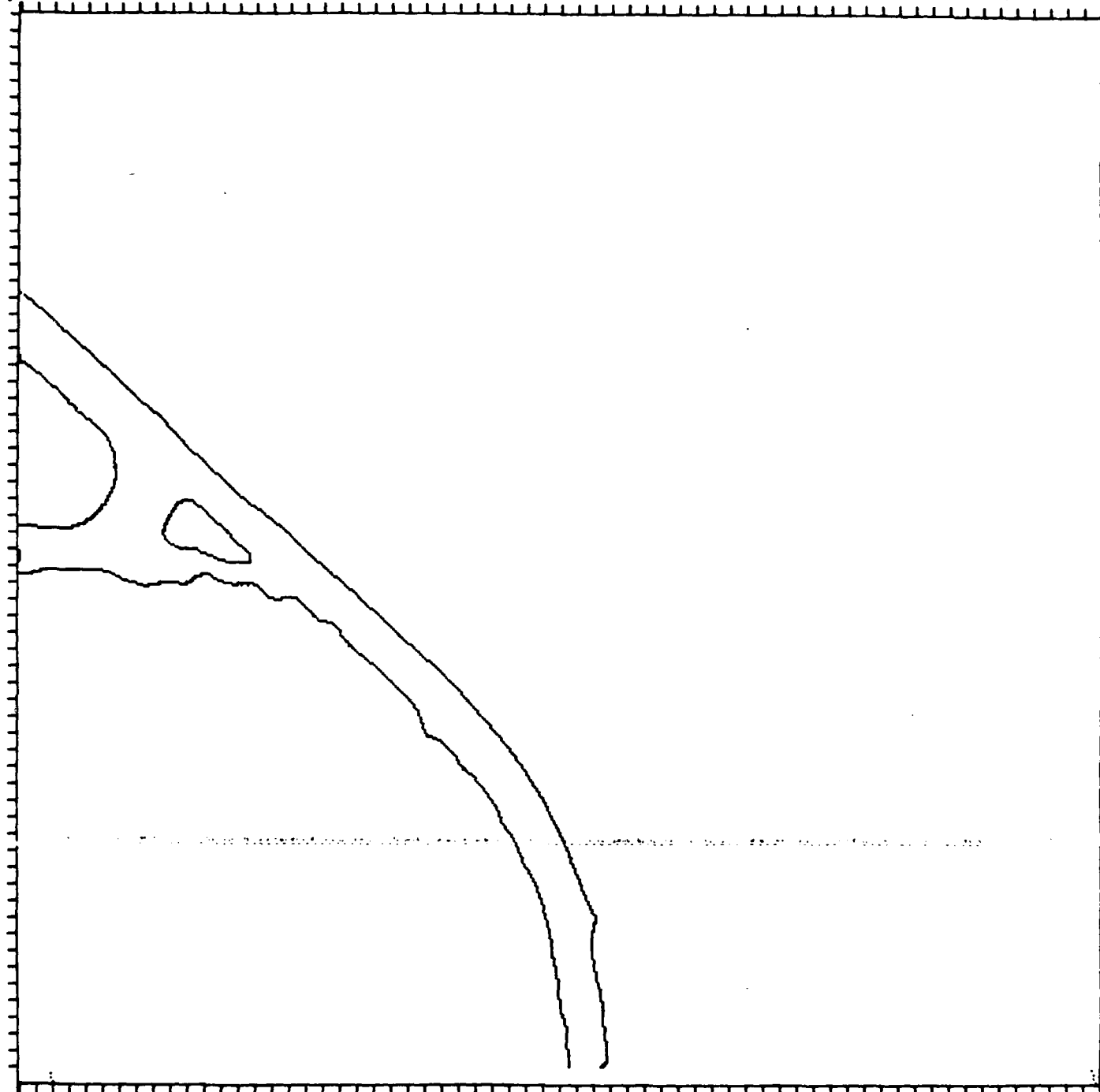


FIGURE 38

STEM 7 - Filtered Barren Class

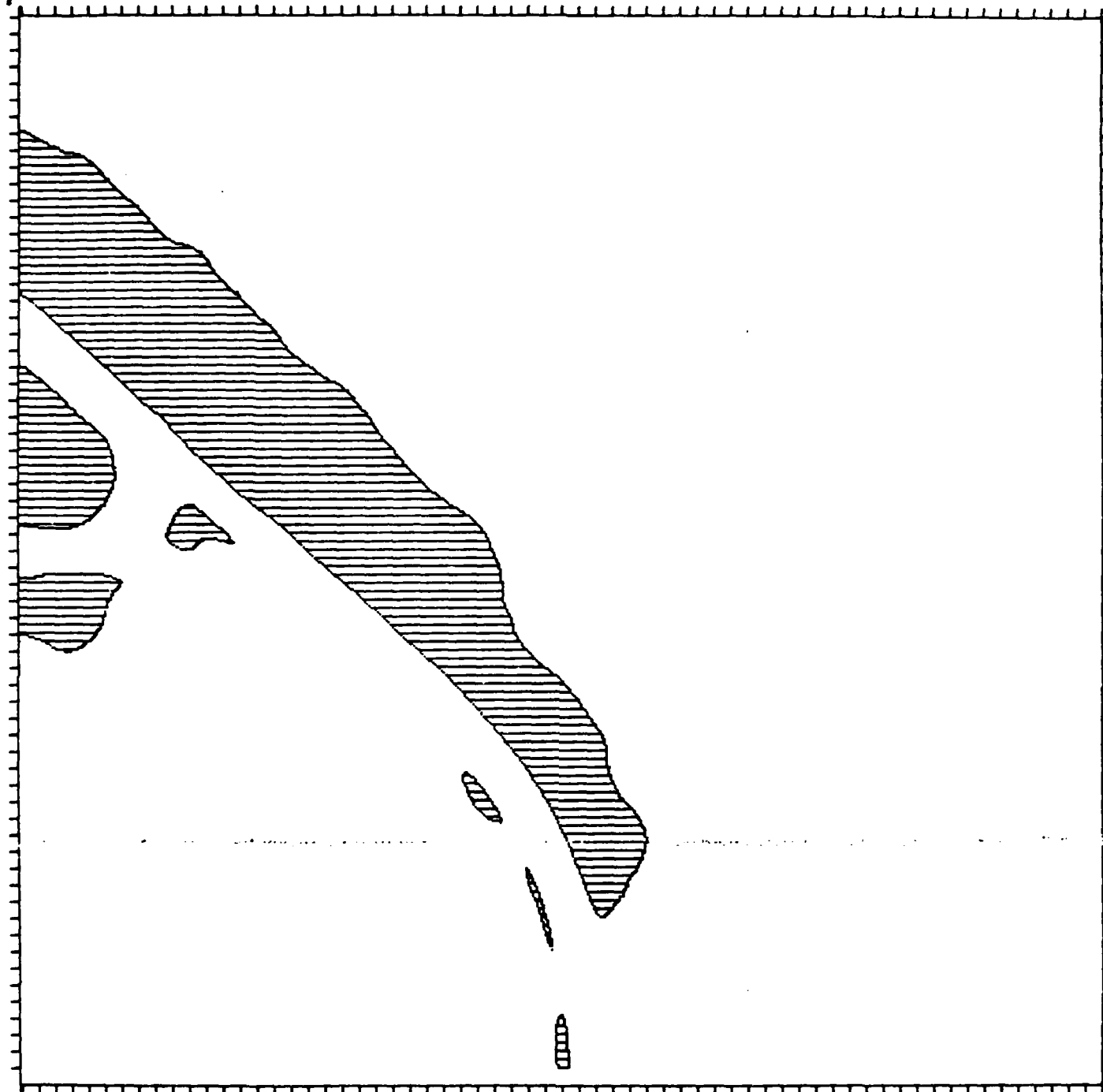


FIGURE 39

STEM 7 - Filtered Grassland Class

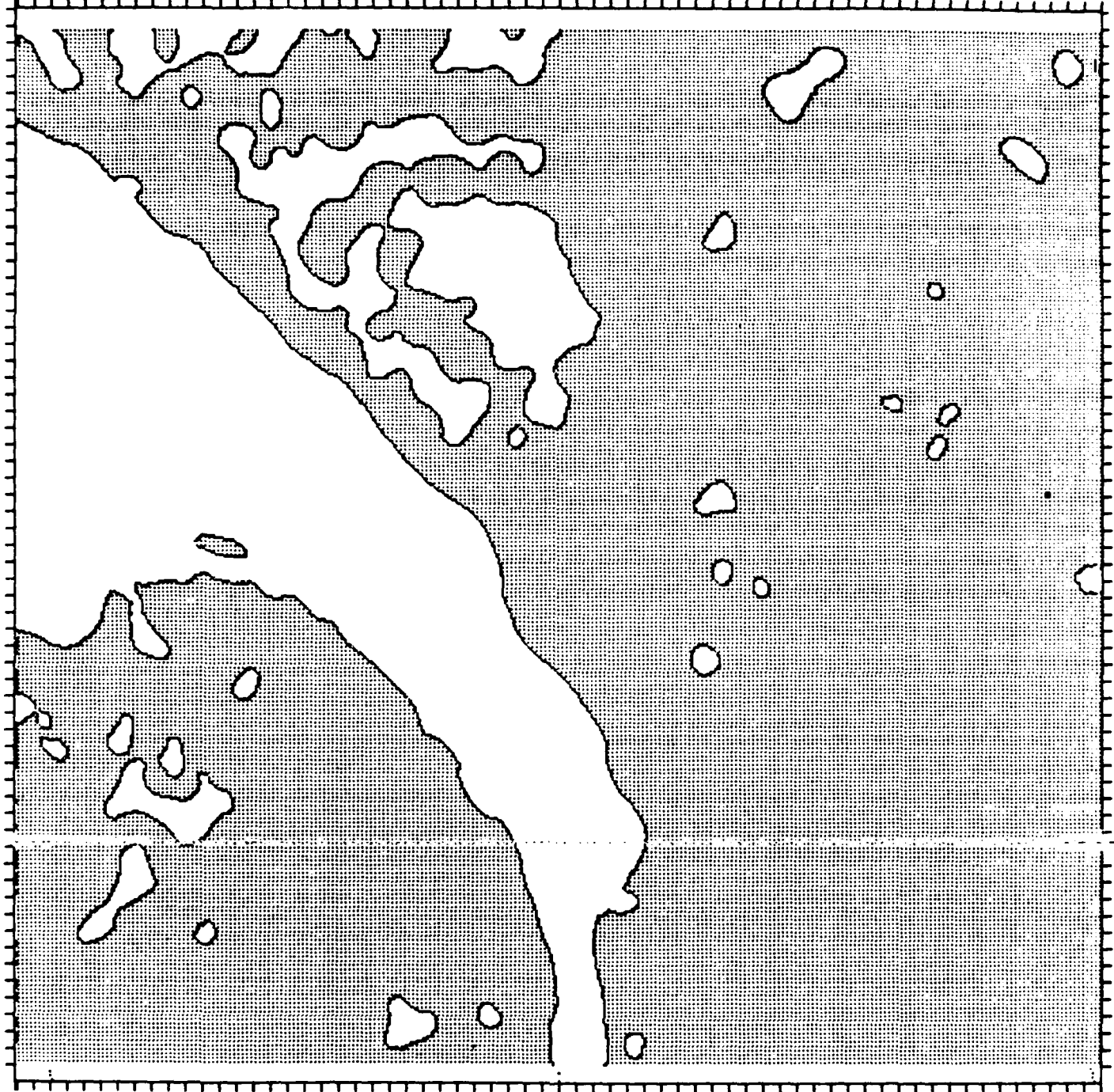


FIGURE 40

STEM 7 - Filtered Forest Class

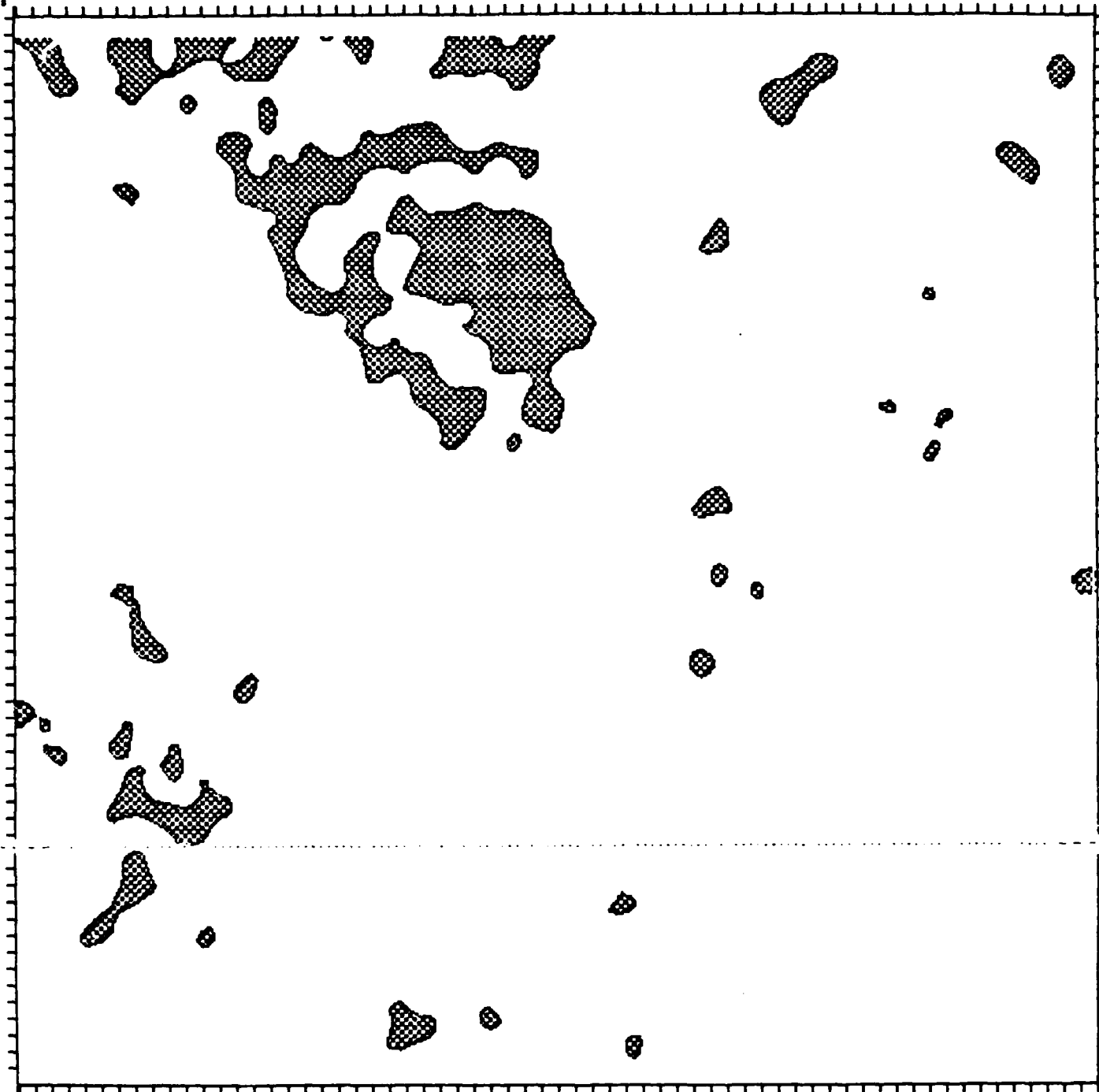


FIGURE 41

STEM 7 - Filtered Dark Tree Class



FIGURE 42
STEM 7 - Filtered Vegetation Classes



FIGURE 43

STEM 7 - Forest Canopy Theme

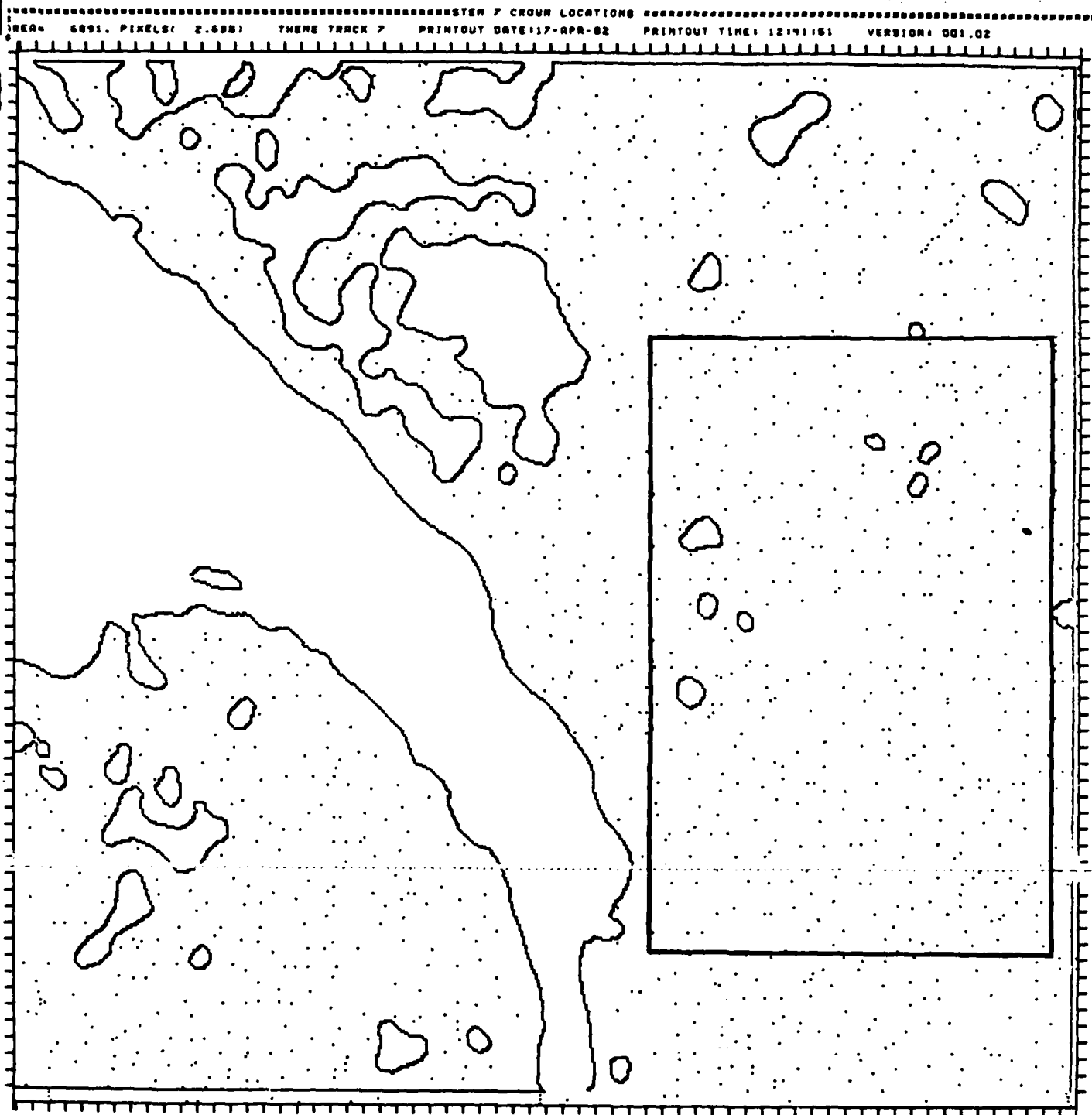


FIGURE 44

Stem 7 - Tree Location Theme

177 Stems/ha

C. Stem 8 Processing Results

This test site was without doubt the most difficult encountered. The digitized area, presented as it was without the benefit of image context is hard to interpret, even on a visual basis. Crowns are well defined only on the left side of the image, and the area appeared to contain mature trees. The remaining half of the image is probably brush. It has a coarse texture similar to forest, but no definition of individual crowns. Isolated crowns cast long shadows on the surrounding area indicating the vegetation does not stand high enough to be forest. The transition between the two areas is gradual enough that no clear vegetation class boundary could be mapped, either visually or by interactive means. Since the test site is completely covered with indistinct vegetation, no classes or boundaries were extracted. Crowns were poorly defined, worse in fact than in other sites from the same image. Initial efforts to extract crown locations were quite discouraging but the frustration of trying to analyze an unworkable test site finally lead to a significant improvement in the crown extraction sequence. On this data set and in general, the operator has had difficulty handling canopy situations where trees appear in more than one tone. In fact this is the primary reason for the "dark forest" class extracted from most of the test sites. A locally normalizing operator was used with considerable success to improve individual crown definition. The operator simply divided the grey level for each pixel by the local mean, computed over an area spanning three or four crowns. As long as stands were larger than this in area individual crowns are normalized to about the same range of grey levels.

The extracted crown locations are valid only on the left side of the area where distinct crowns exists.

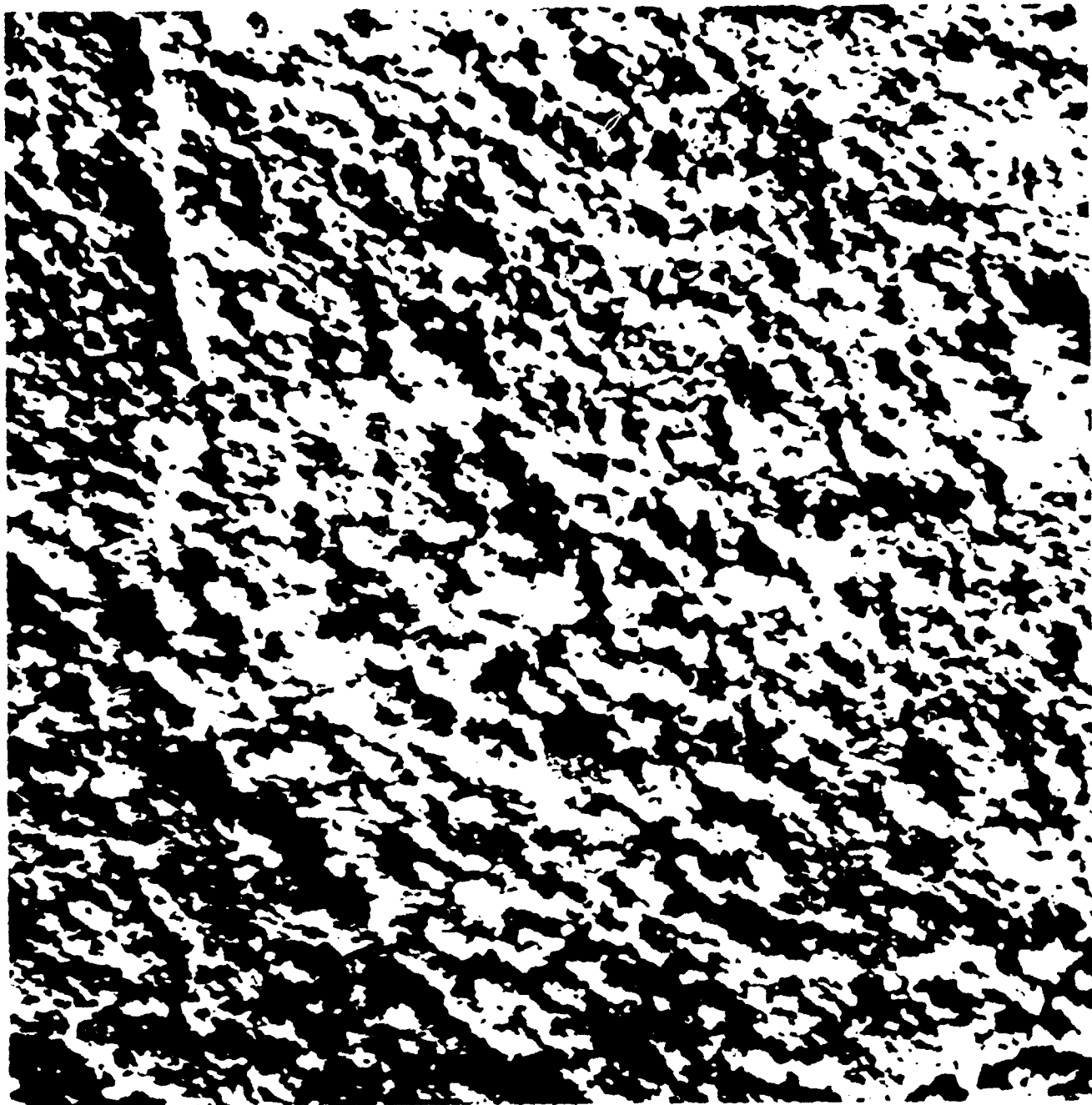
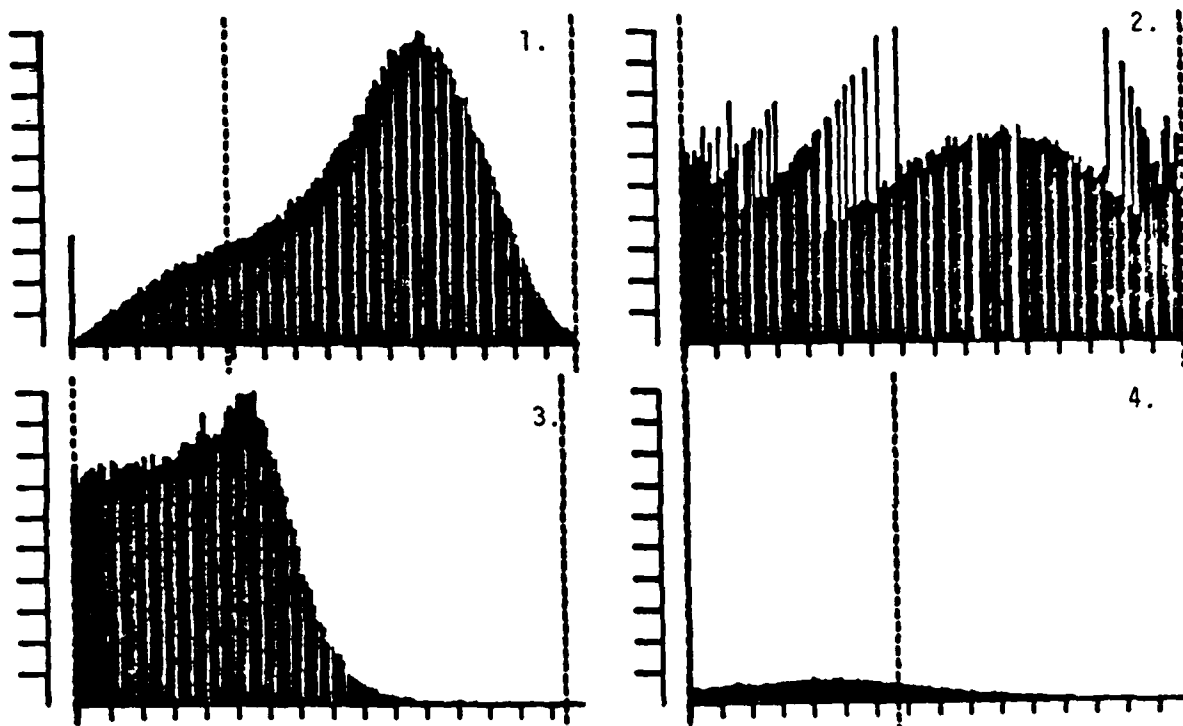


FIGURE 45

STEM 8 - Histogram Equalization Stretch



TRAINING SUMMARY 18-APR-82 20:54:36+
 8 LE UB DEL PEAK MEAN VAR +
 1 39 127 89 1201. 24.2 81.7 +
 2 0 127 128 2848. 63.41367.3 +
 3 0 123 124 4356. 31.1 330.1 +
 4 0 53 54 40157. 21.4 310.6 +
 TRAINING AREA=216338. PIXELS +
 ALARMED AREA=143965 PIXELS(54.9%) +
 TYPE CHS, (C)OMPARE, L(O)AD, E(X)IT

STEM 8
 1. RAW DATA WITH SHADOW THRESHOLD
 2. HISTOGRAM EQUALIZATION STRETCH
 3. LOCALLY NORMALIZED HIST STRETCH
 4. CROWN TEMPLATE WITH THRESHOLD

FIGURE 46

STEM 8 - Key Histograms

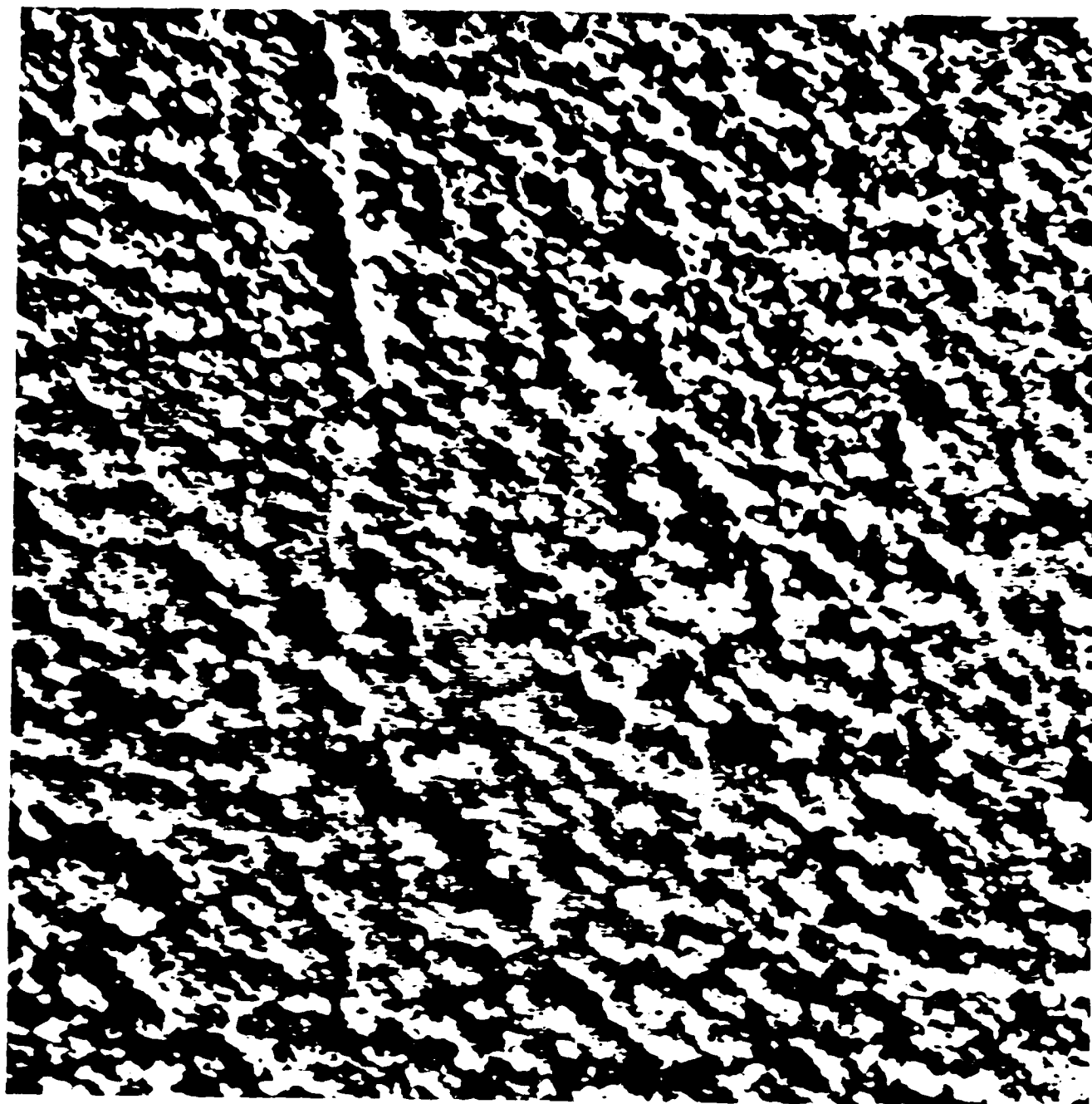


FIGURE 47

STEM 8 - Locally Normalized Histogram Stretch

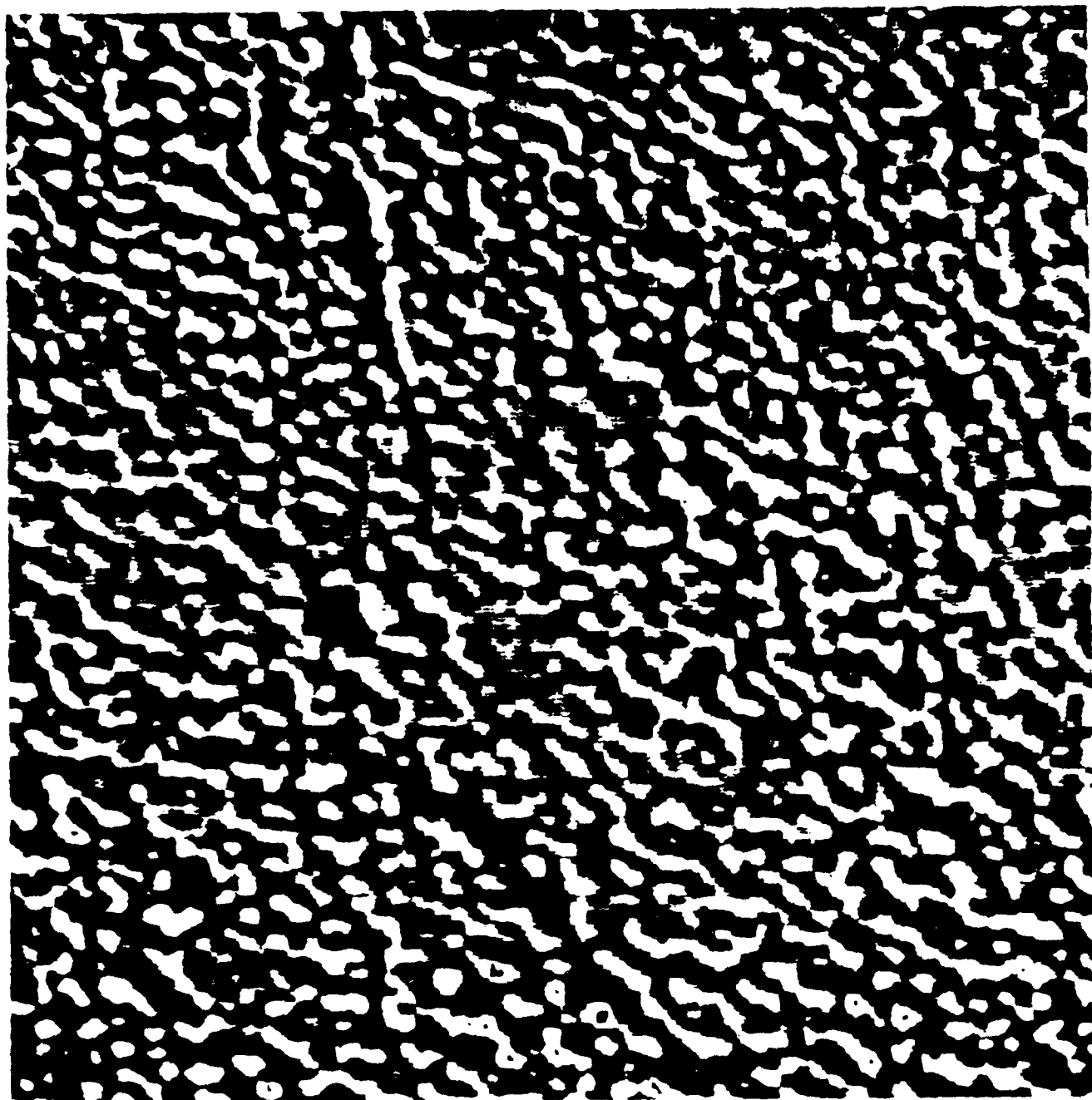


FIGURE 48

STEM 8 - Crown Template

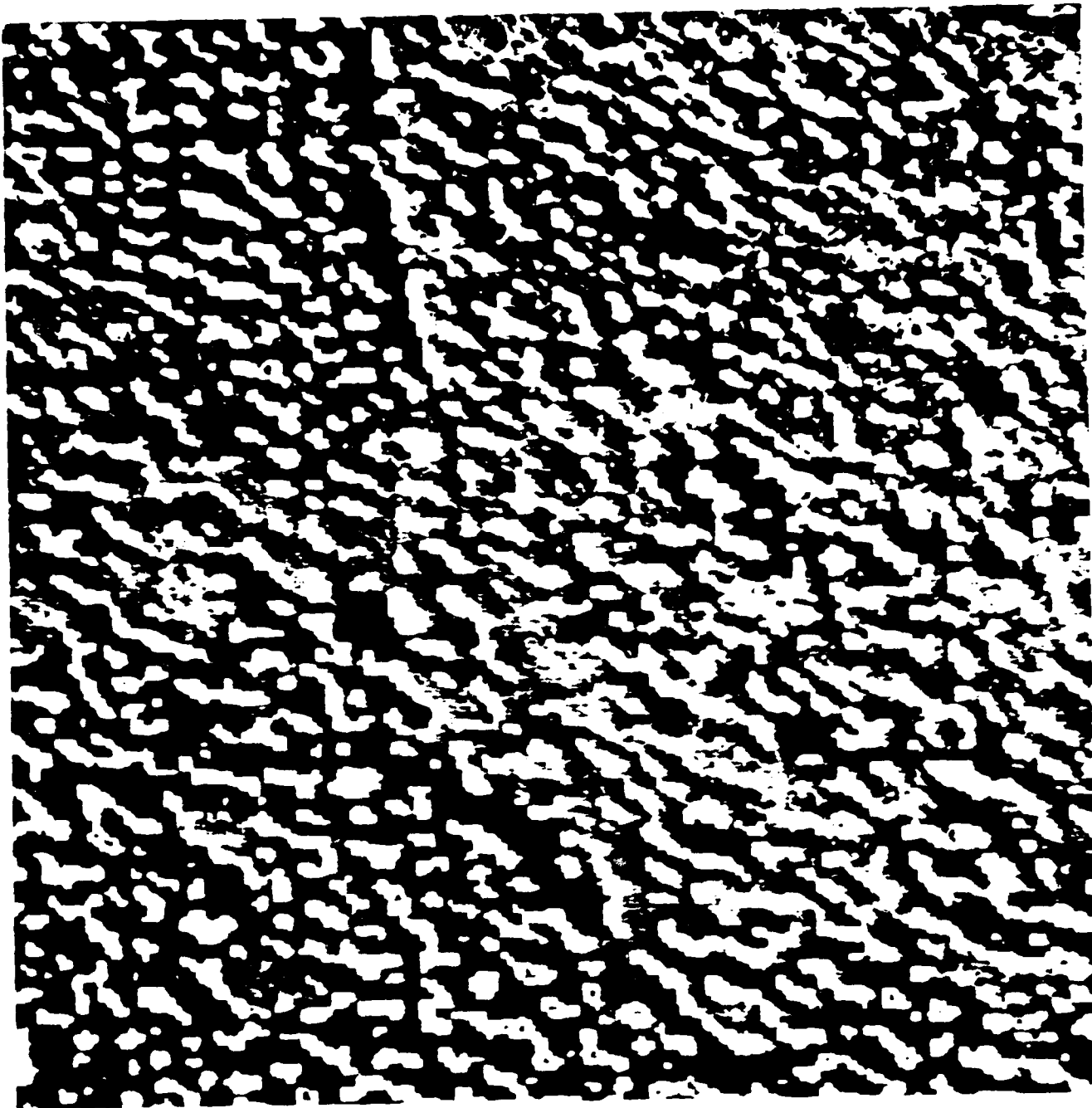


FIGURE 49

STEM 8 - Crown Template Slice

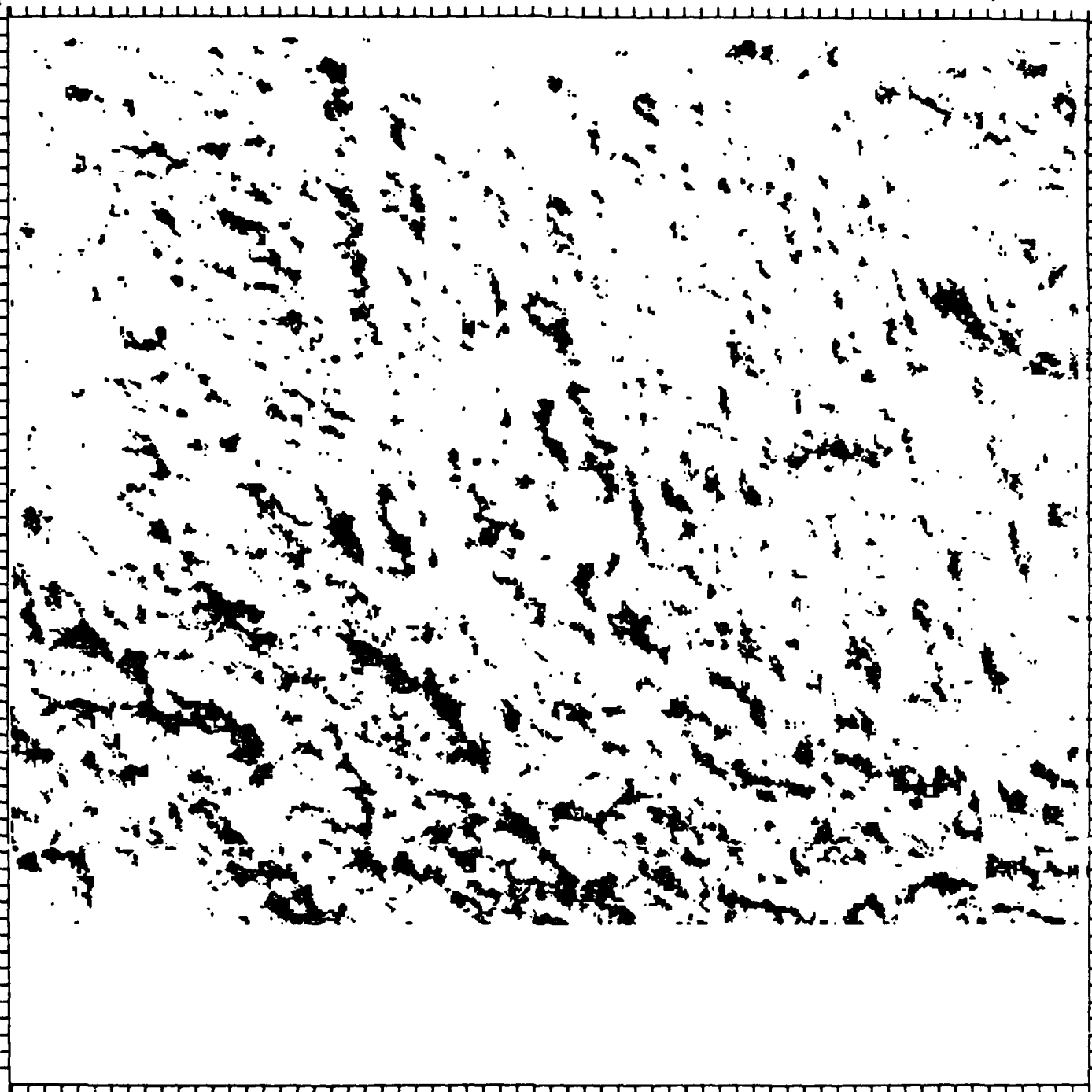


FIGURE 50

STEM 8 - Tree Shadow Areas

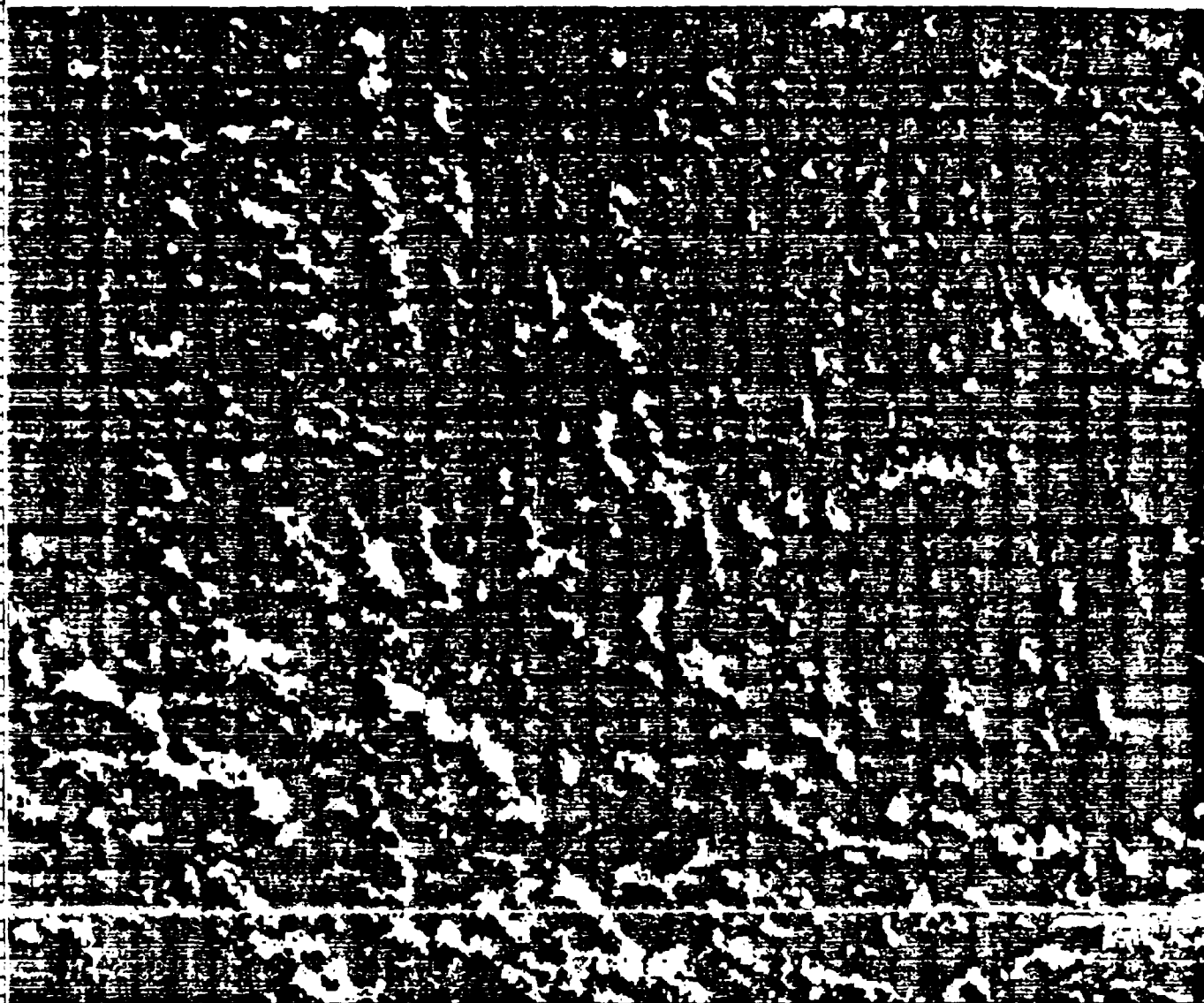


FIGURE 51

STEM 8 - Forest Canopy

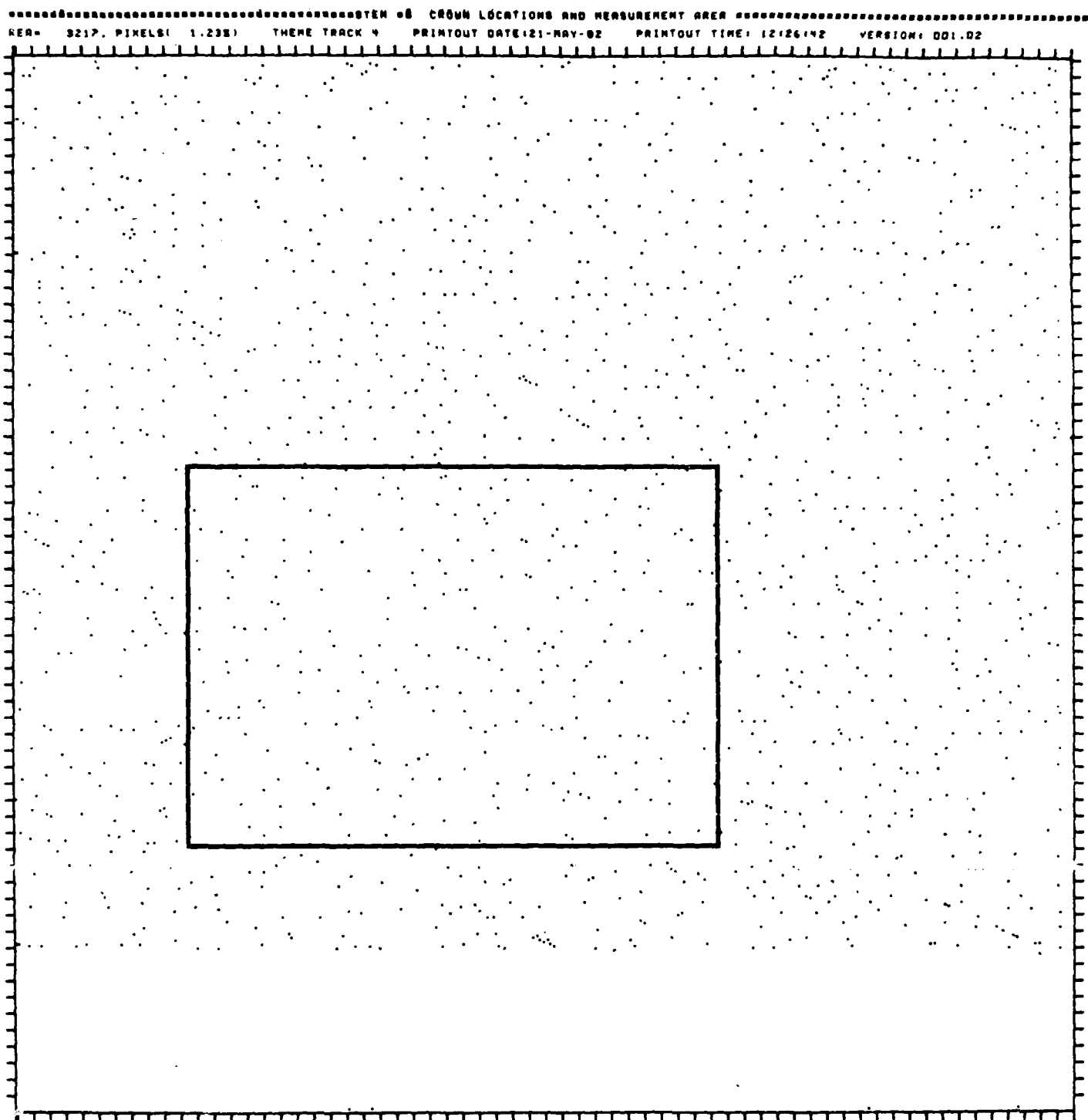


FIGURE 52
STEM 8 - Crown Location Theme
104 Stems/ha

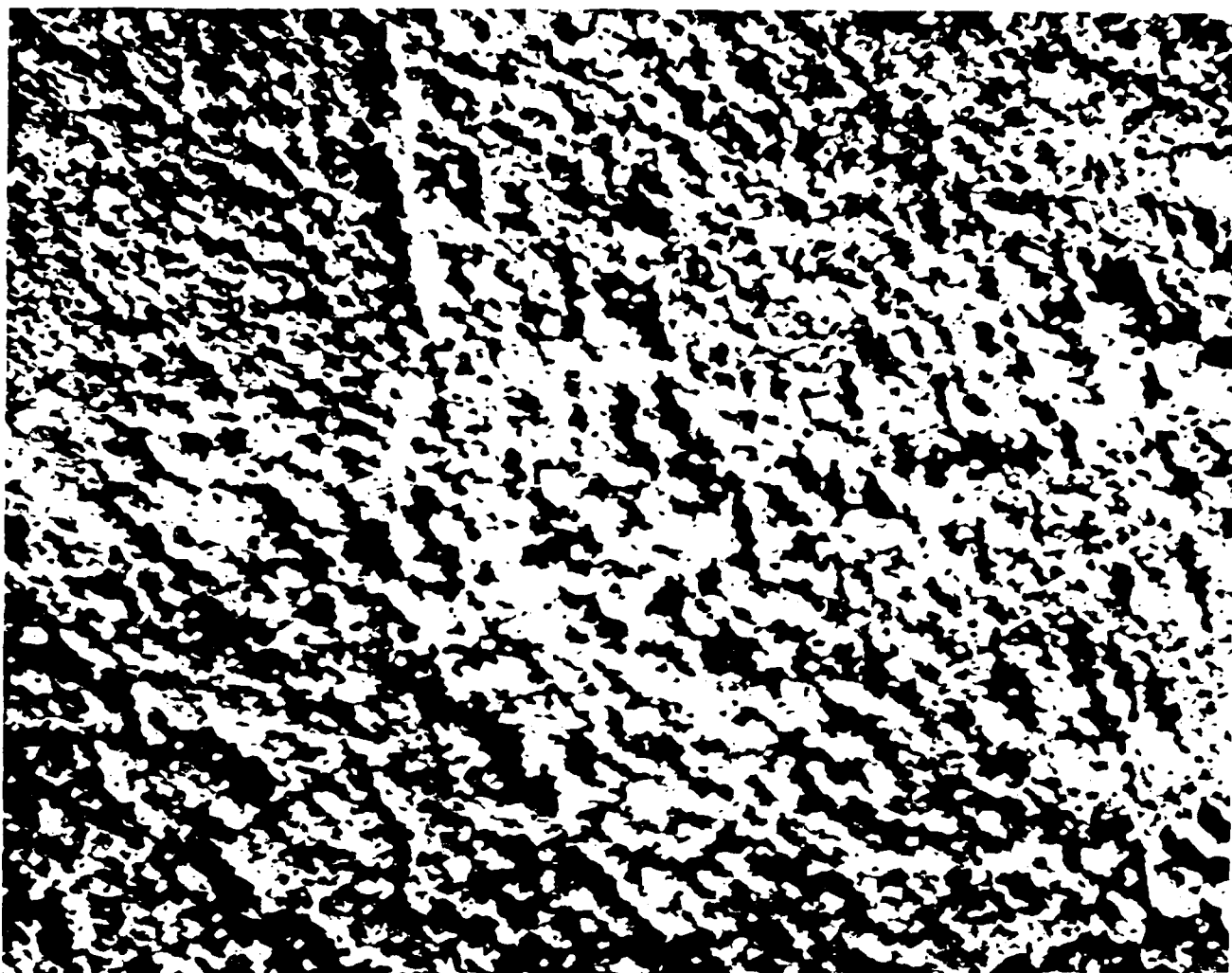


FIGURE 53

STEM 8

CROWN LOCATIONS SUPERIMPOSED ON TREES

D. Stem 9 Processing Results

This area was primarily dense and mature deciduous forest with full canopy closure. There appears to be a species mix as individual trees are imaged with a considerable range of brightnesses. One small area in the upper left corner contains solid coniferous forest and another in the upper right is barren or lightly vegetated wetland.

Extracting the vegetation categories was moderately difficult. Differentiating between deciduous forest and wetland was very easy, but extracting the coniferous forest was not. A very poor coniferous class was sliced from grey level and smoothed texture, and then the theme filter was used to transform the result into a satisfactory class.

Stem location within the deciduous forest was made difficult by the brightness mix of the various species, and direct application of crown template was not effective. Local intensity normalization was again used to eliminate the brightness problem. This digitized area is probably the best demonstration of the local normalization technique.

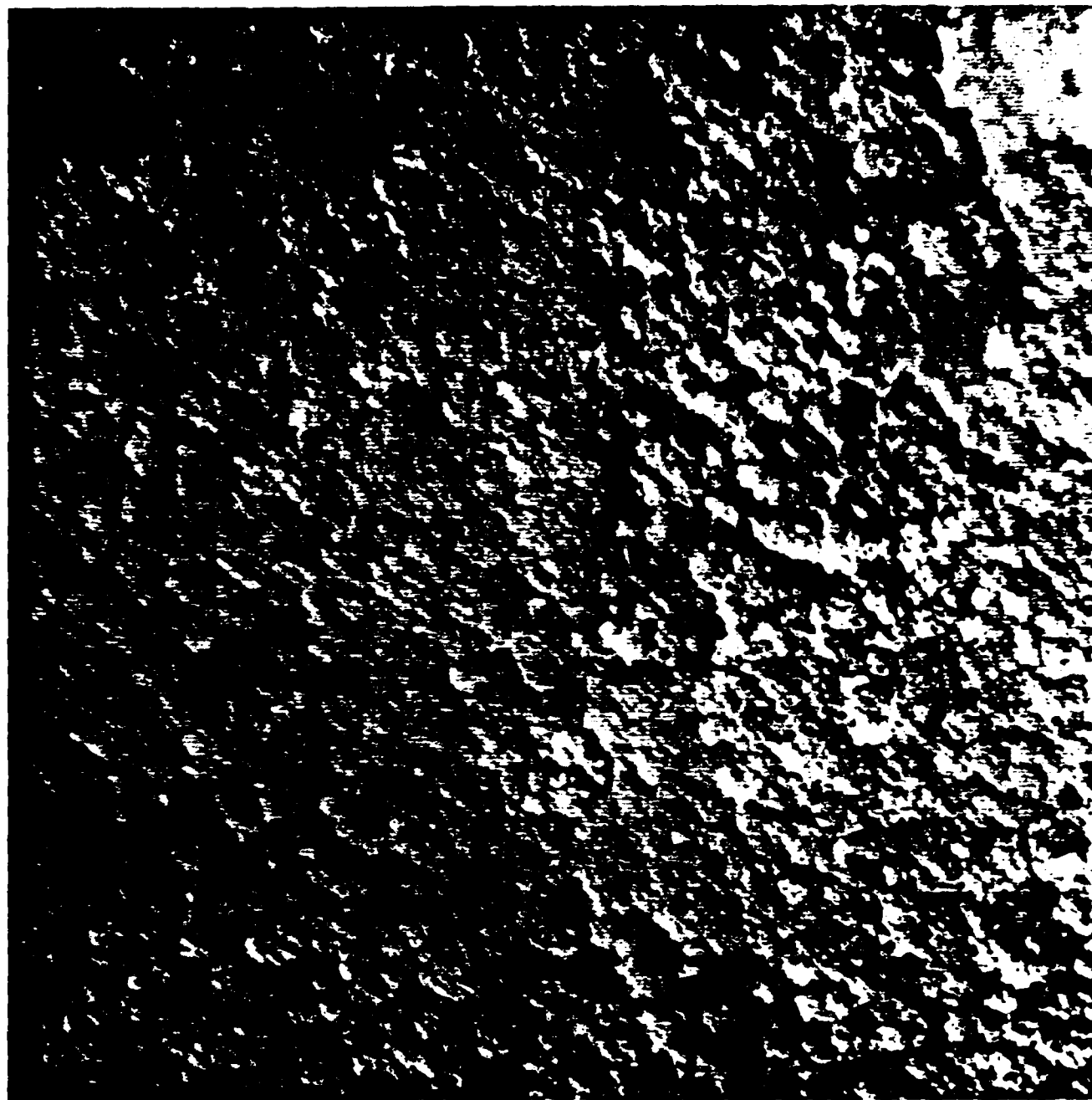


FIGURE 54

STEM 9 - Raw Data



FIGURE 55

STEM 9 - 21 x 21 Pixel Smoothed Texture

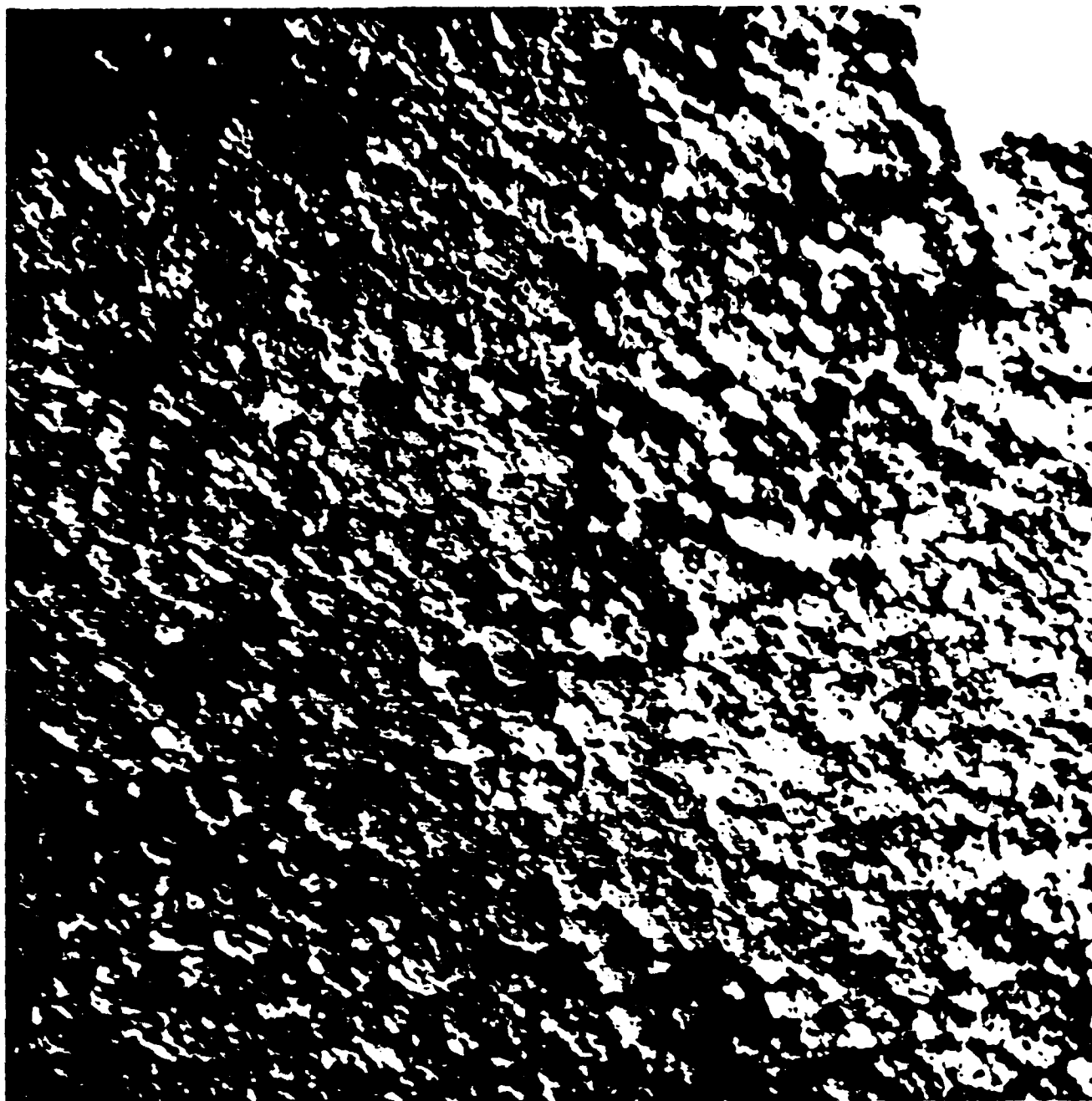


FIGURE 56

STEM 9 - Histogram Equalization Stretch

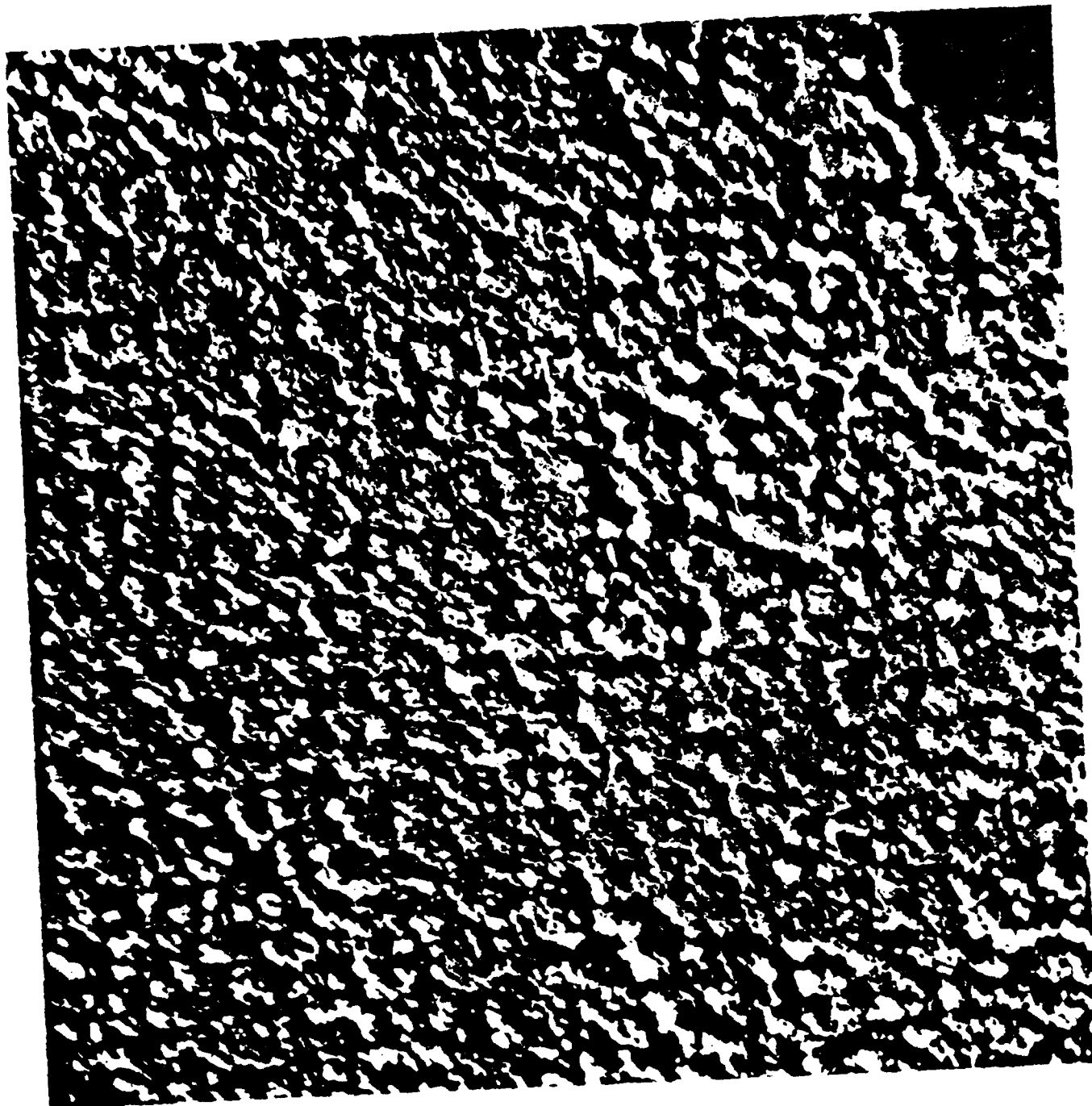


FIGURE 57

STEM 9 - Normalized Histogram Stretch

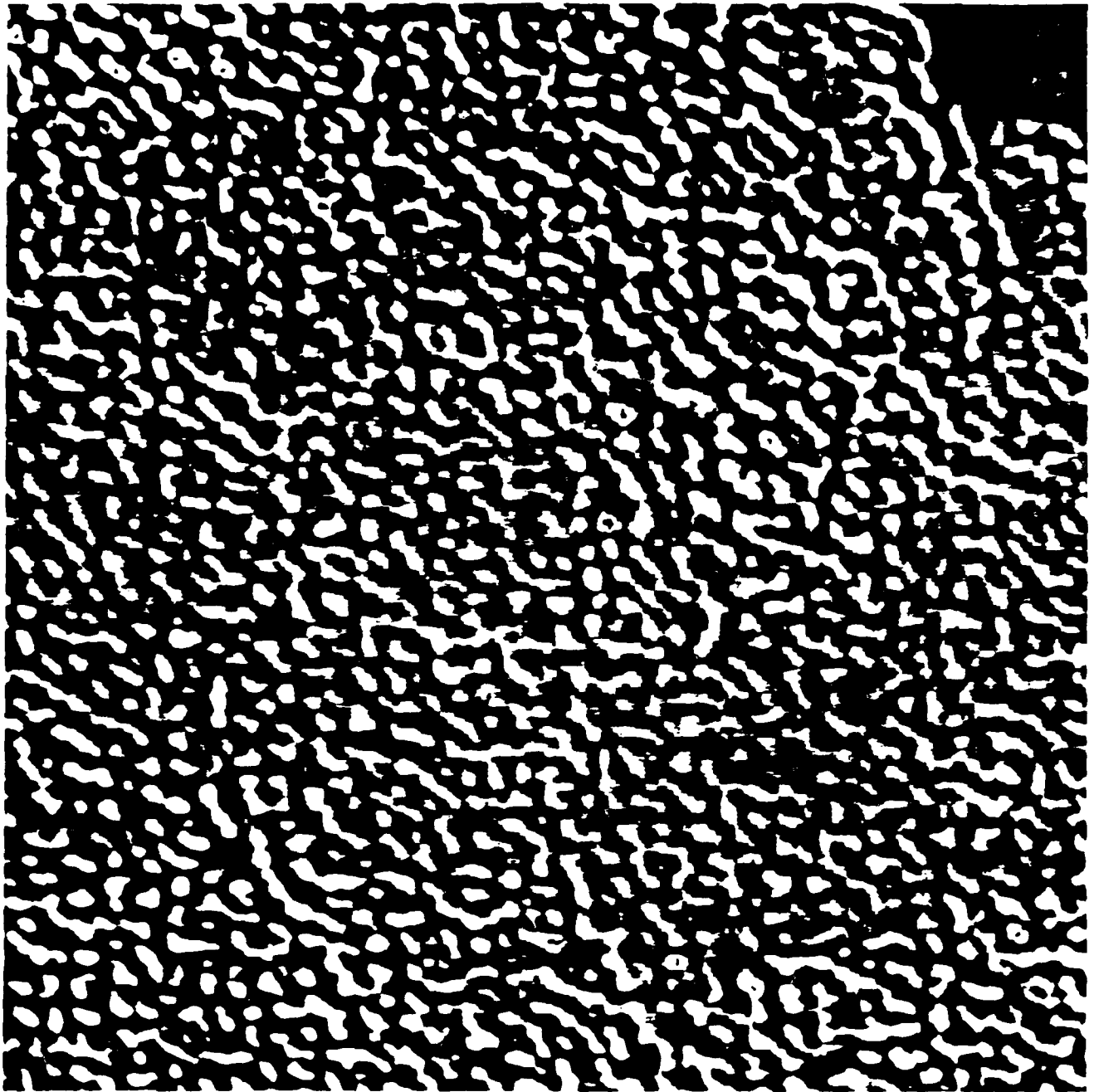
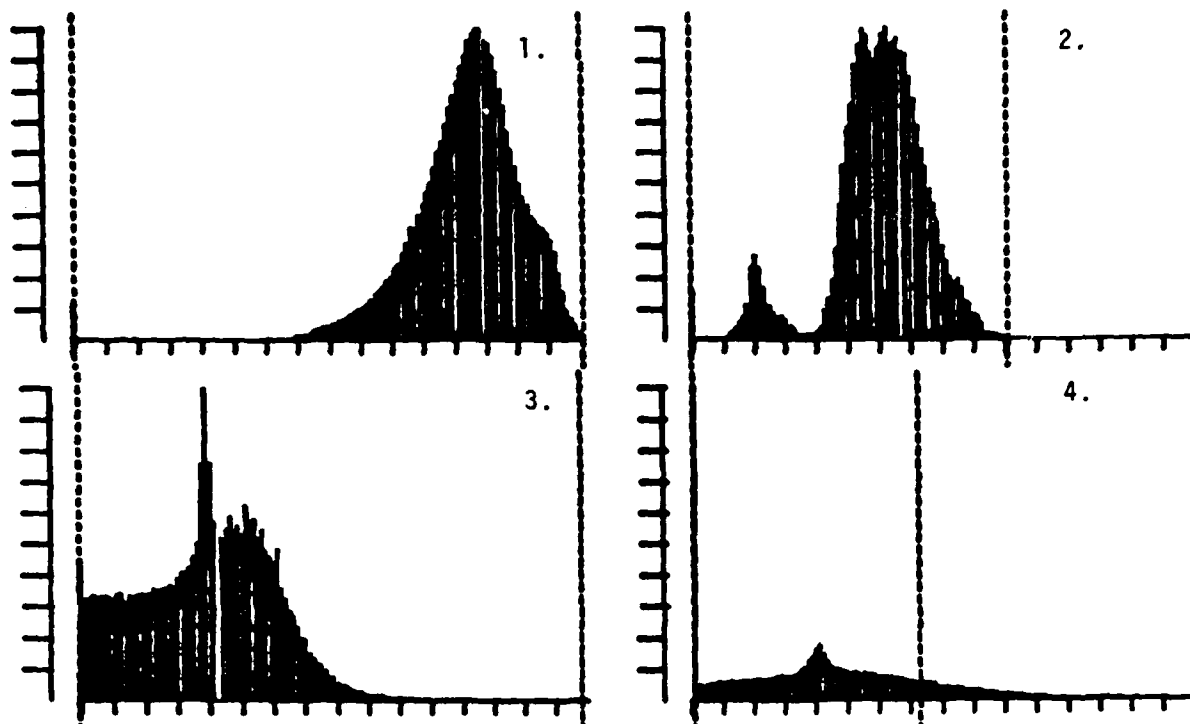


FIGURE 58

STEM 9 - Crown Template Output



TRAINING SUMMARY 18-APR-82 12:26:36+
 8 LE UB DEL PEAK MEAN UAR +
 1 0 127 128 9076. 98.6 211.4 +
 2 0 30 31 10105. 48.1 156.9 +
 3 0 127 123 9924. 31.1 873.3 +
 4 0 57 58 37386. 25.2 313.9 +
 TRAINING AREA=252730. PIXELS +
 ALARMED AREA=215190. PIXELS(82.1%) +
 TYPE CHS. (C)OMPARE. L(O)AD. E(X)IT

STEM 9
 1. RAW DATA
 2. SMOOTHED TEXTURE
 3. LOCALLY NORMALIZED DATA
 4. CROWN TEMPLATE

FIGURE 59

STEM 9 - Key Histograms

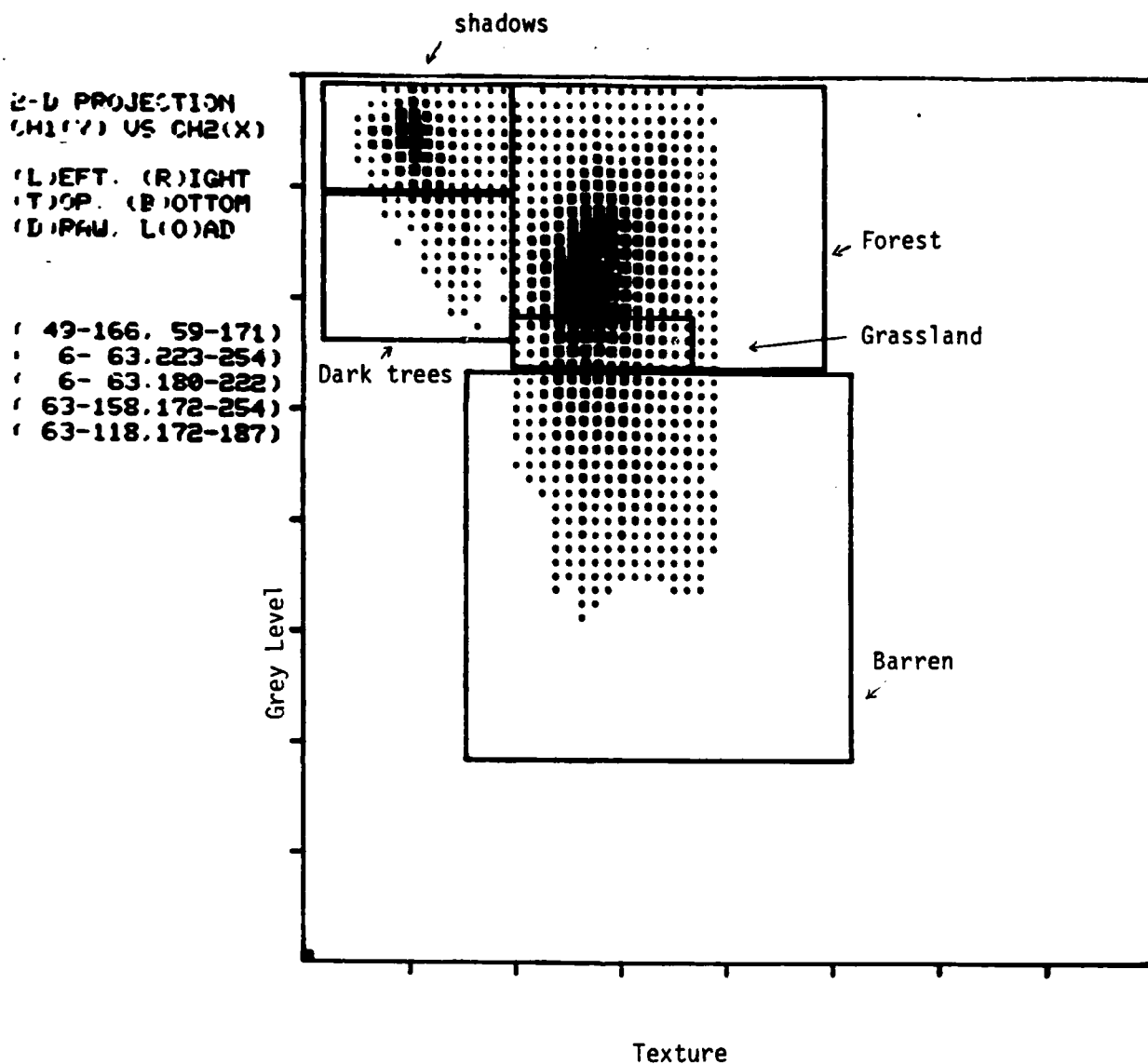


FIGURE 60

STEM 9 - Vegetation Class Signatures

*****STEM 9 BARE AREAS*****
AREA= 2790. PIXELS(1.06%) THEMATIC TRACK 9 PRINTOUT DATE: 18-APR-82 PRINTOUT TIME: 10:47:13 VERSION: 001.02

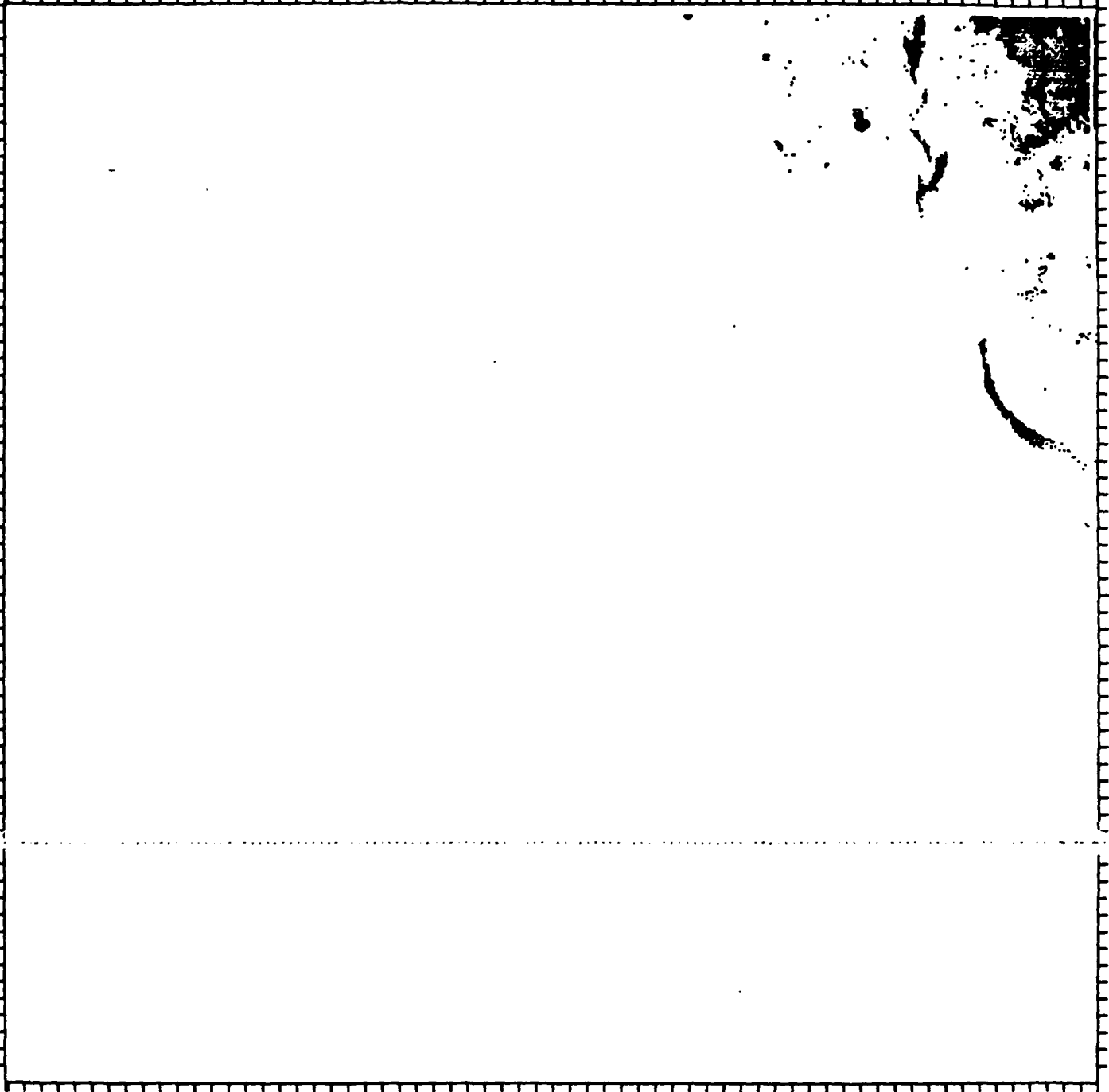


FIGURE 61
STEM 9 - Original Barren Class

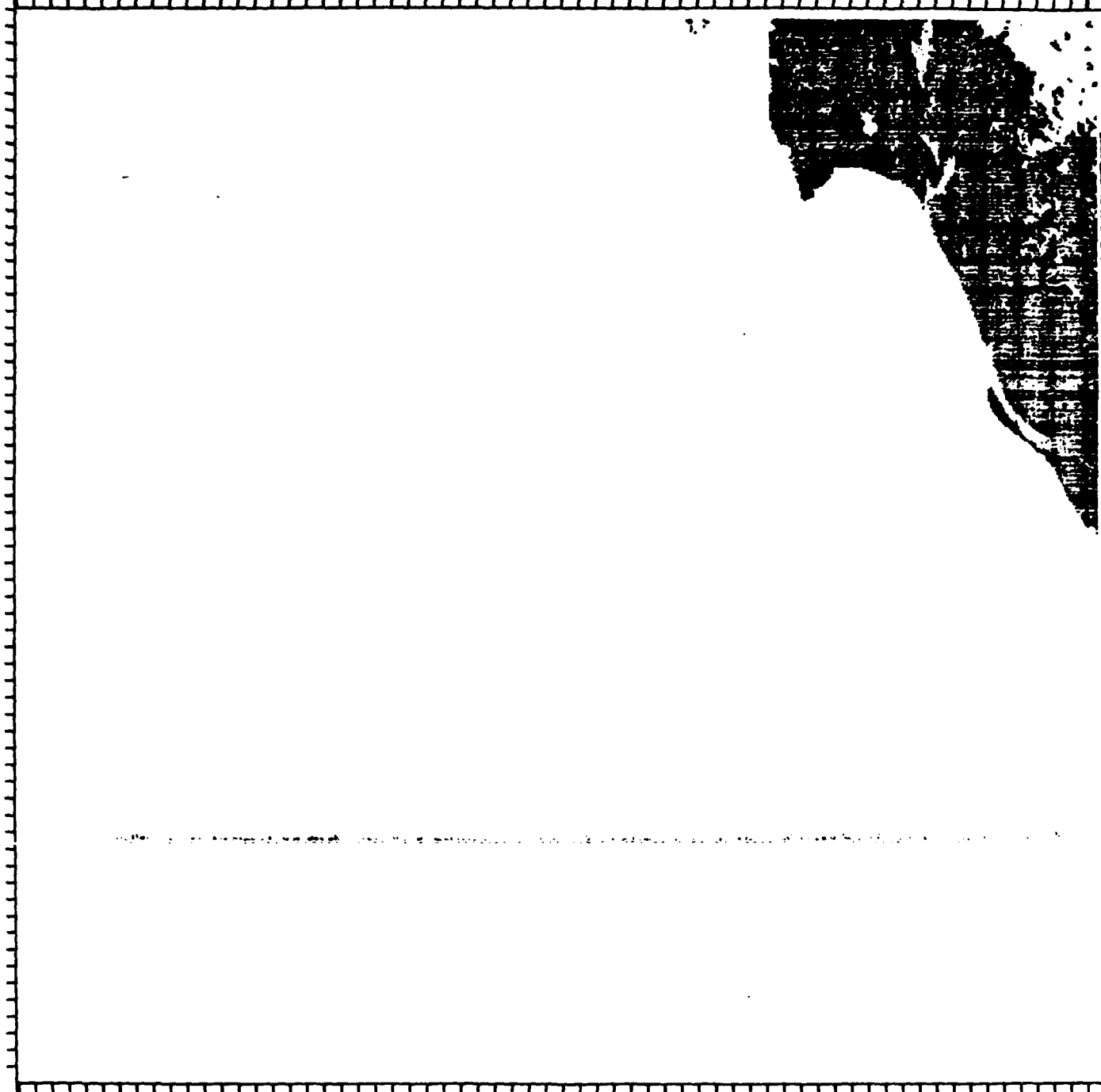


FIGURE 62

STEM 9 - Original Grassland Class

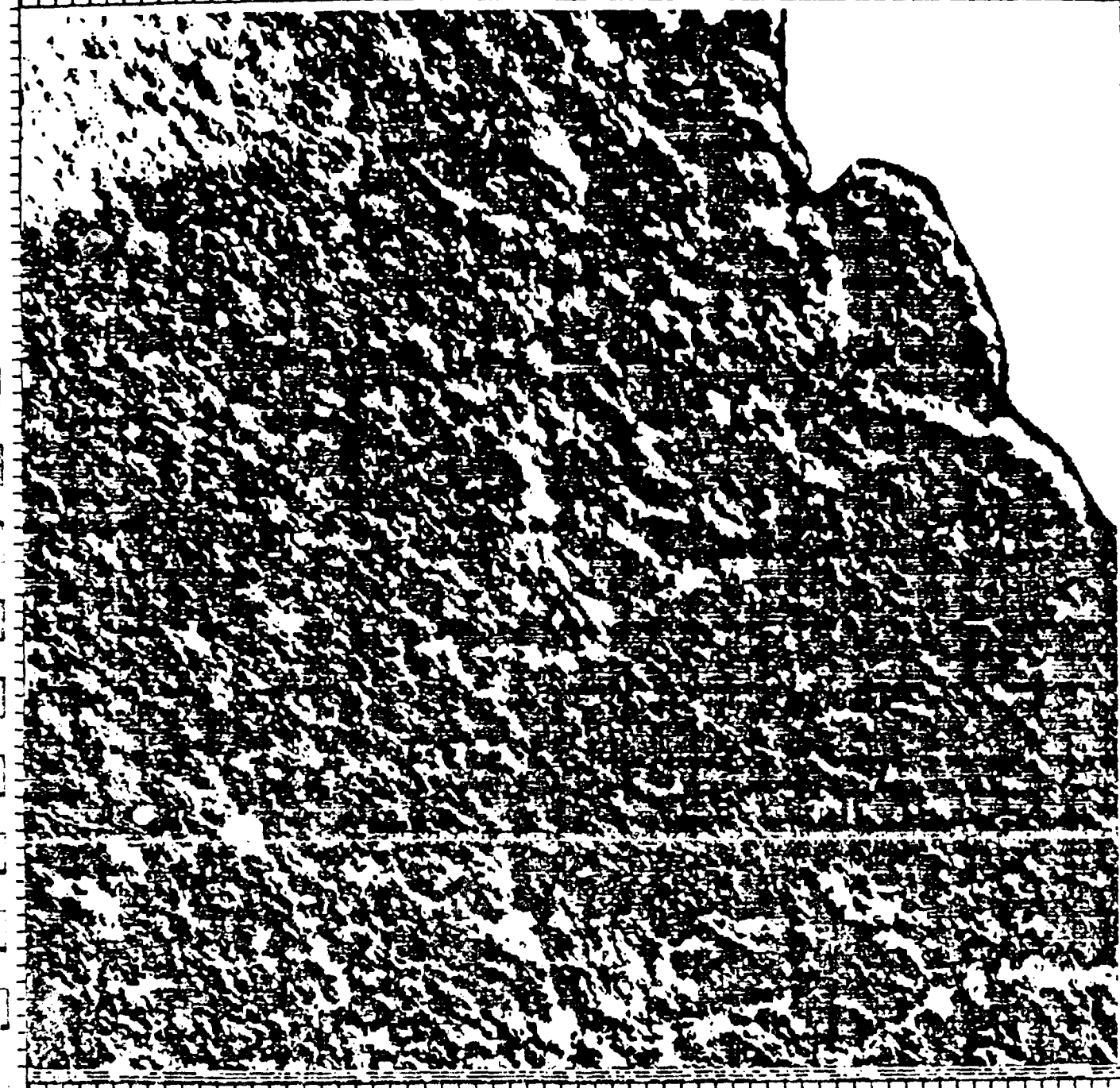


FIGURE 63

STEM 9 - Original Forest Class

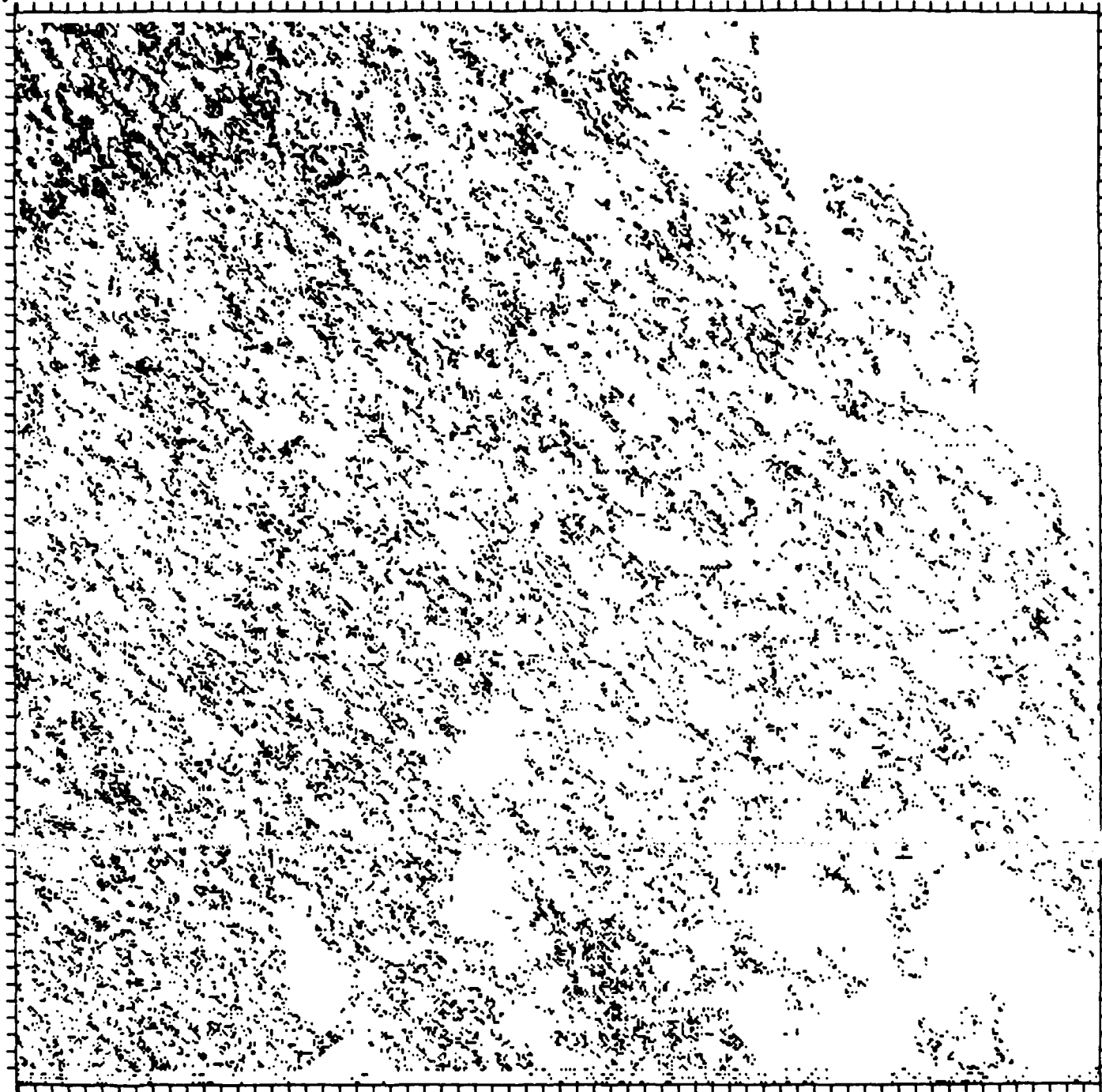


FIGURE 64

STEM 9 - Original Dark Tree Class

AD-A116 881

GENERAL ELECTRIC CO LANHAM MD SPACE SYSTEMS DIV
INTERACTIVE DIGITAL IMAGE PROCESSING FOR TERRAIN DATA EXTRACTION--ETC(U)
MAY 82 T F WESCOTT, W C DALLAM

F/G 9/2

DAAK70-79-C-0153

UNCLASSIFIED

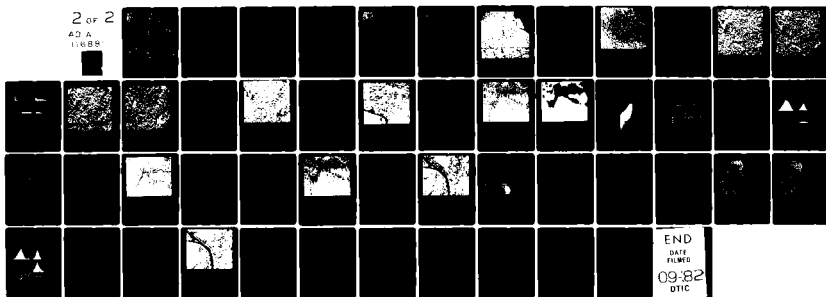
ETL-0294

NL

2 OF 2

43 A

11888



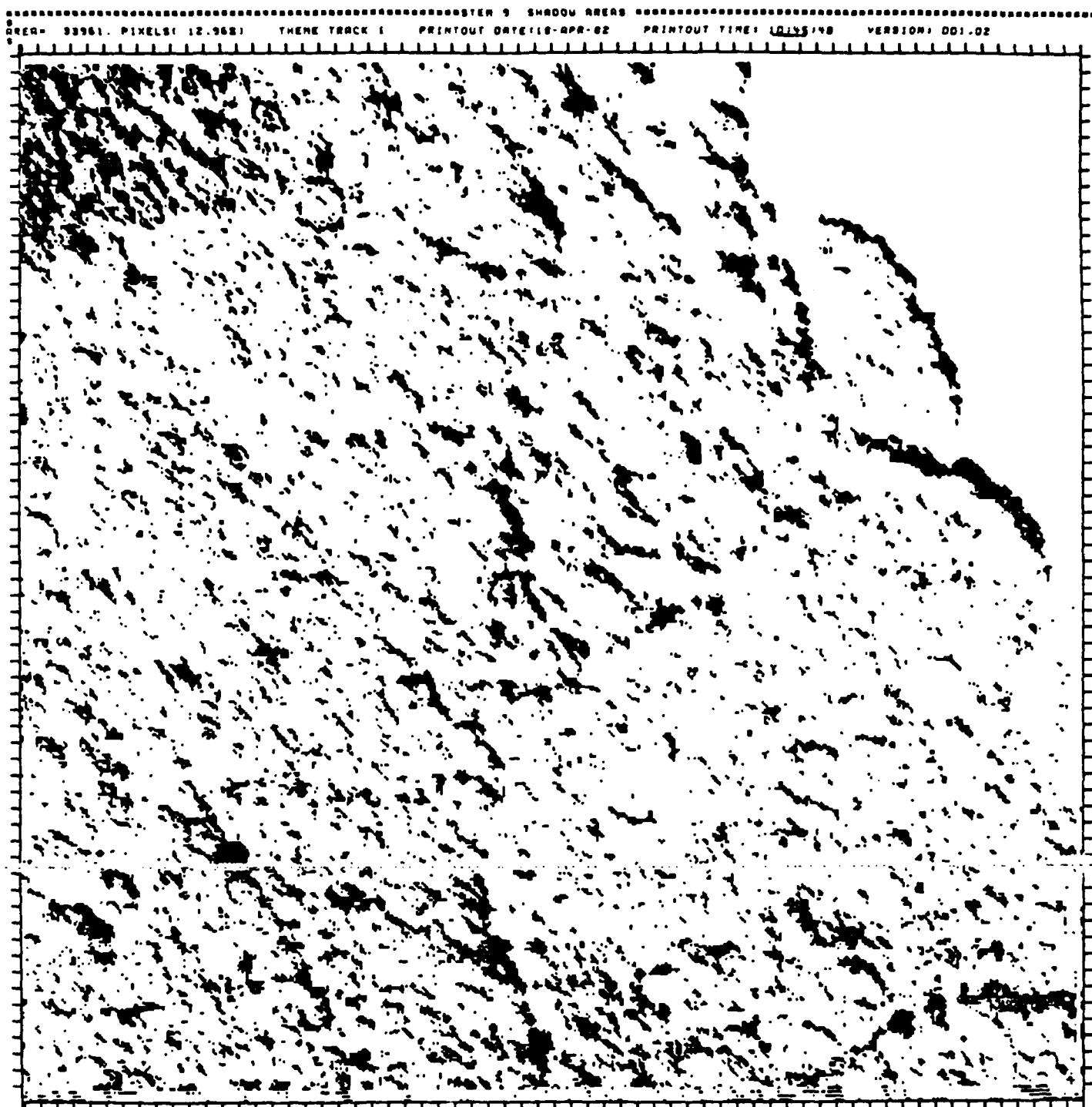


FIGURE 65
STEM 9 - Tree Shadows

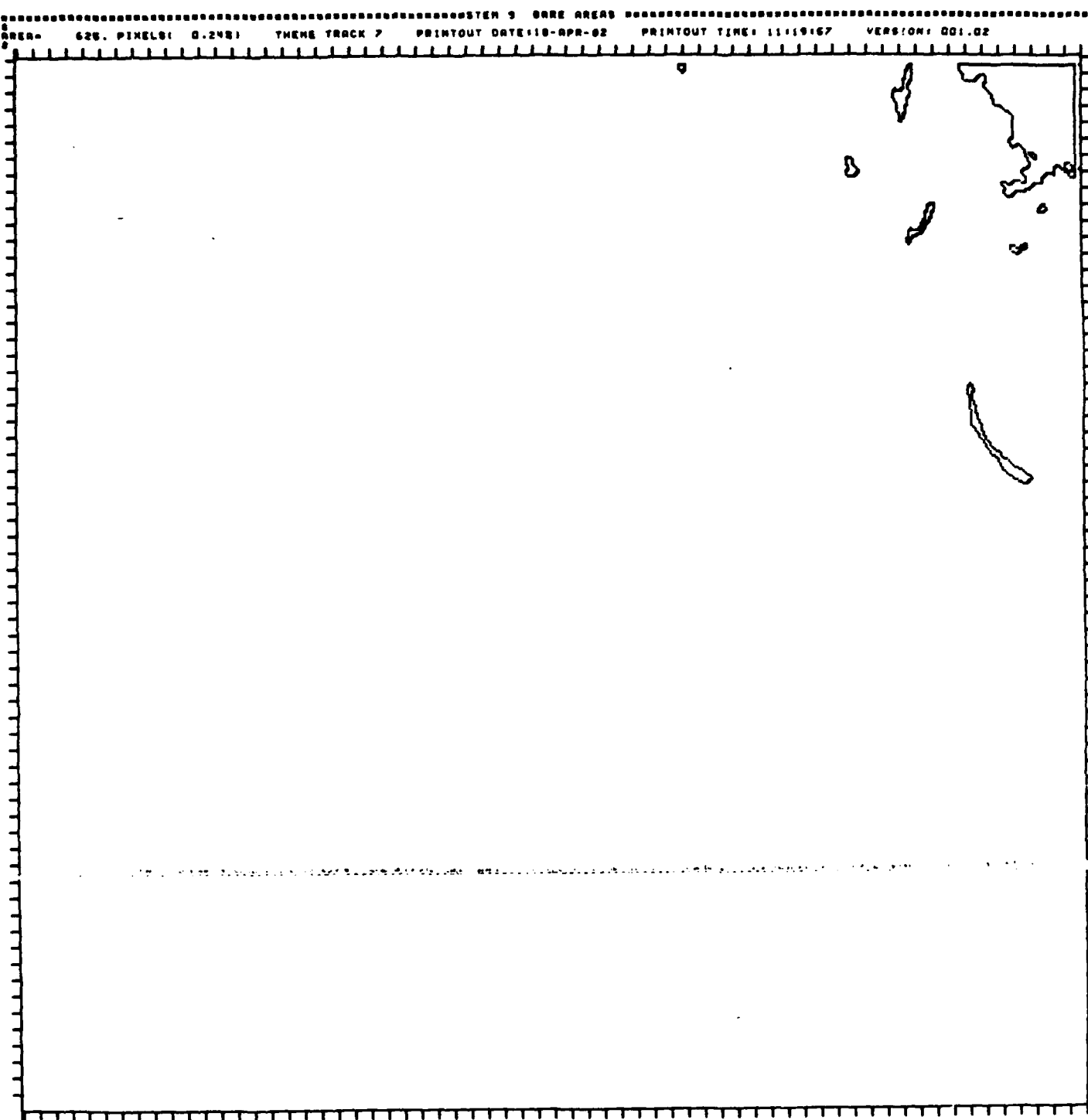


FIGURE 66
STEM 9 - Filtered Barren Class

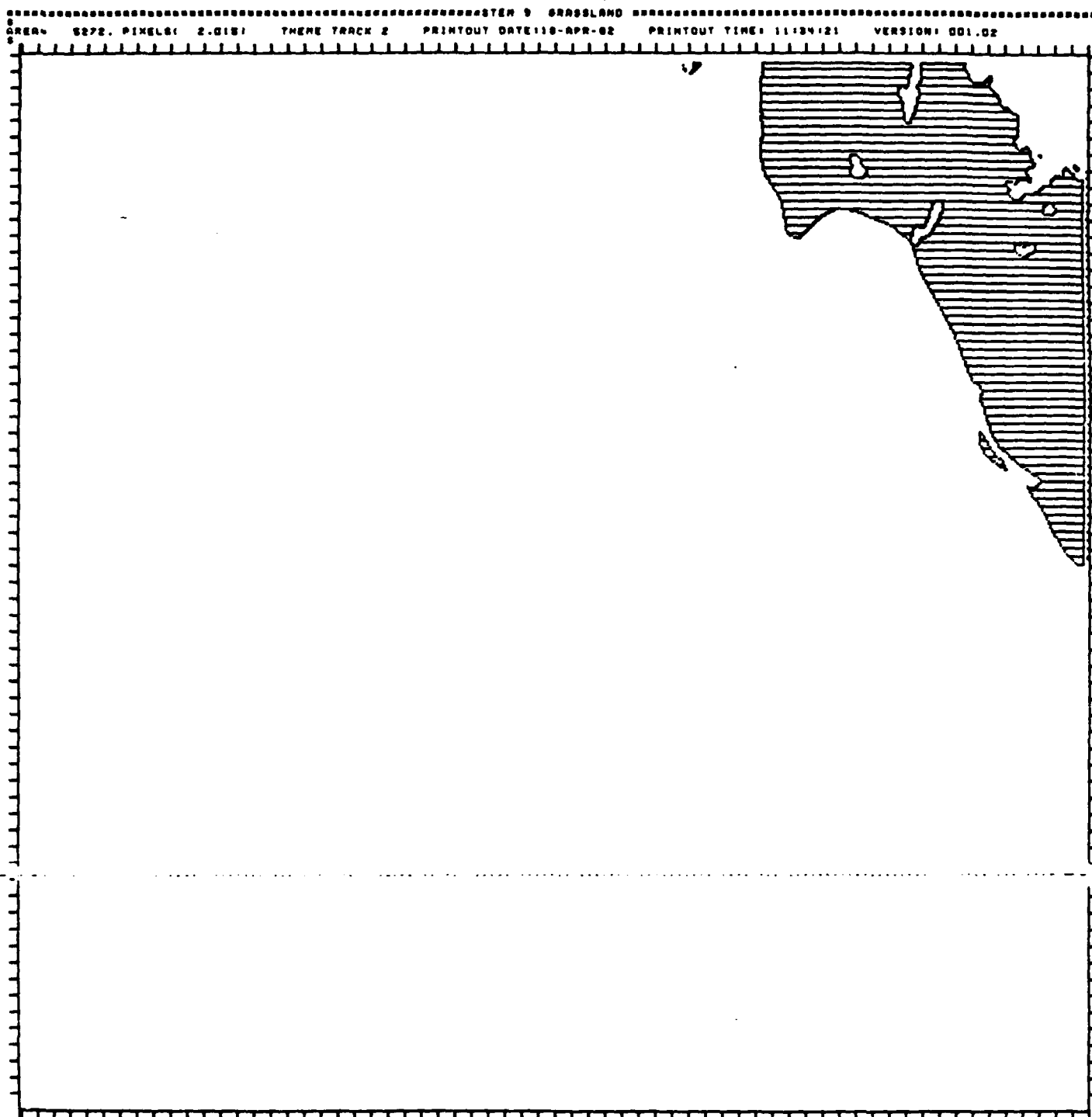


FIGURE 67

STEM 9 - Filtered Grassland Class

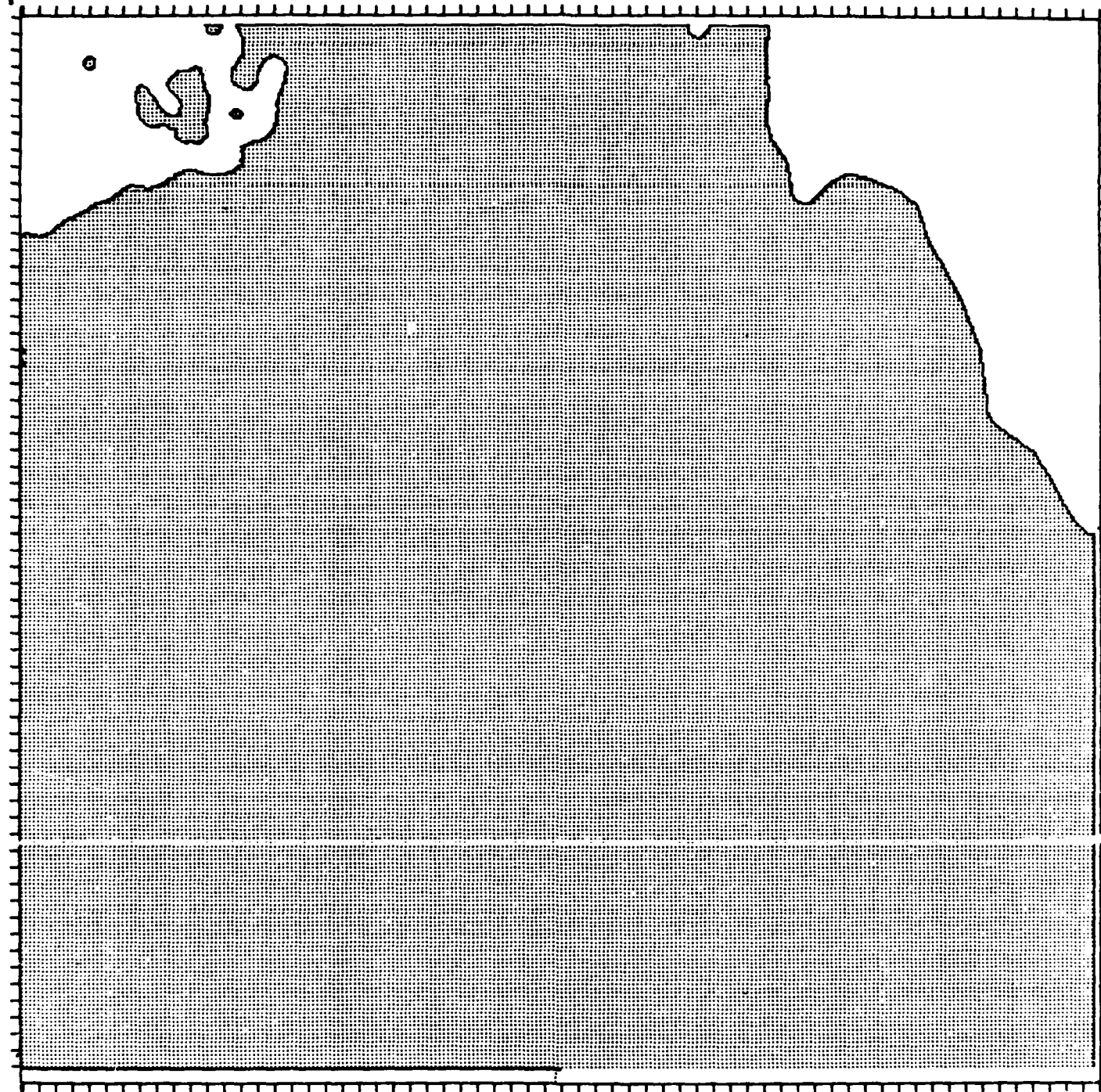


FIGURE 68

STEM 9 - Filtered Forest Class

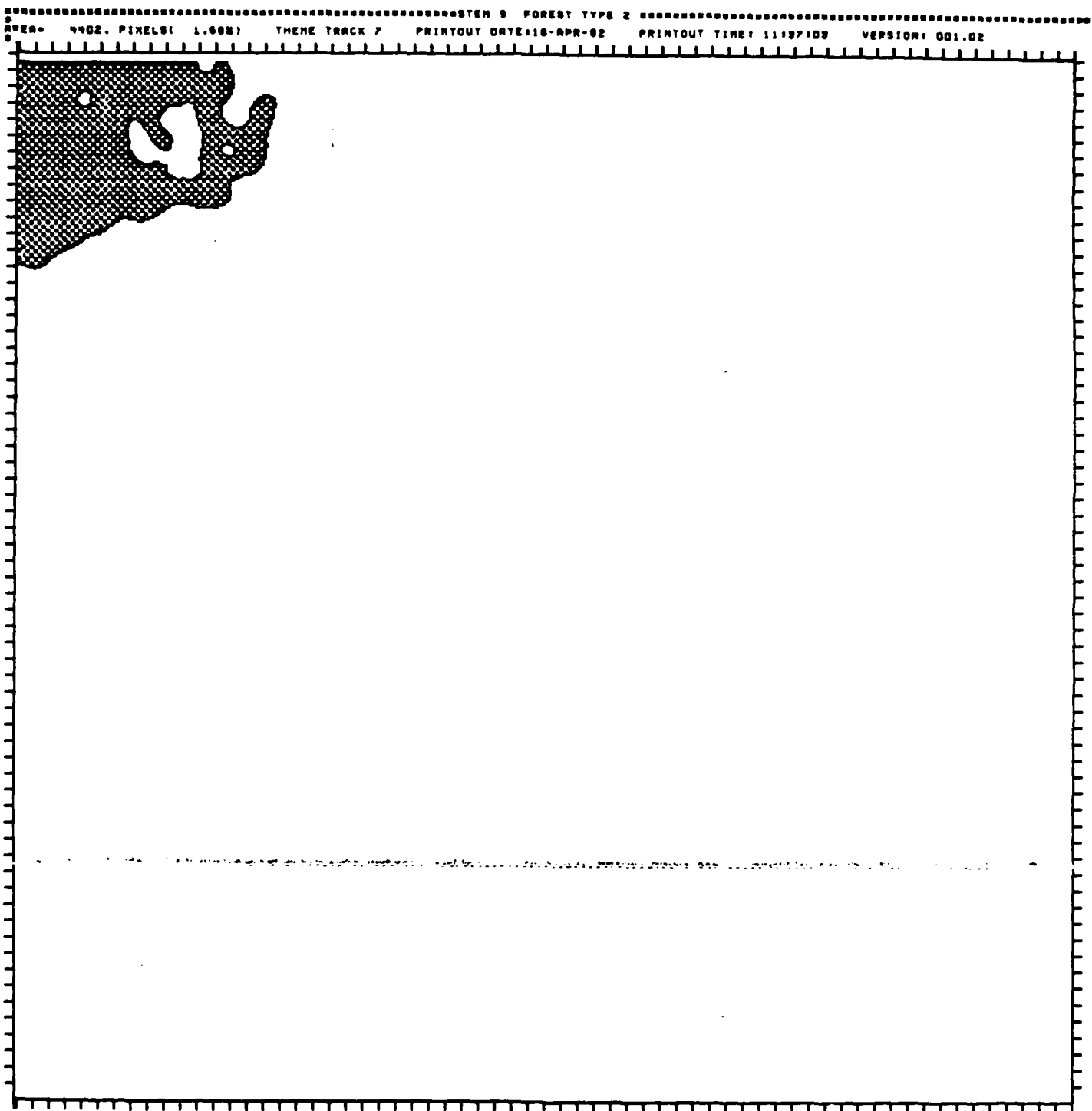


FIGURE 69

STEM 9 - Filtered Dark Tree Class

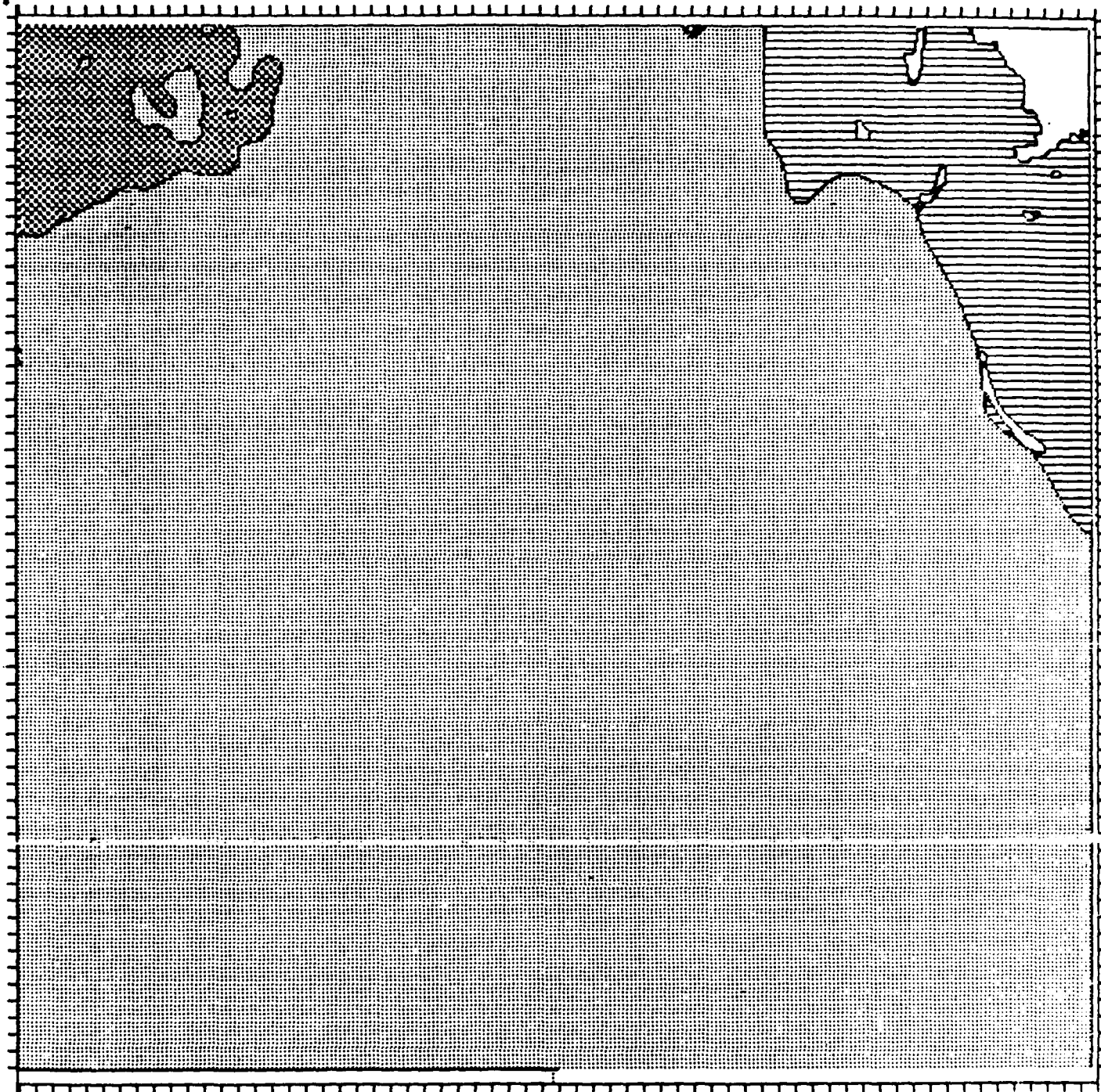


FIGURE 70

STEM 9 - Filtered Vegetation Class

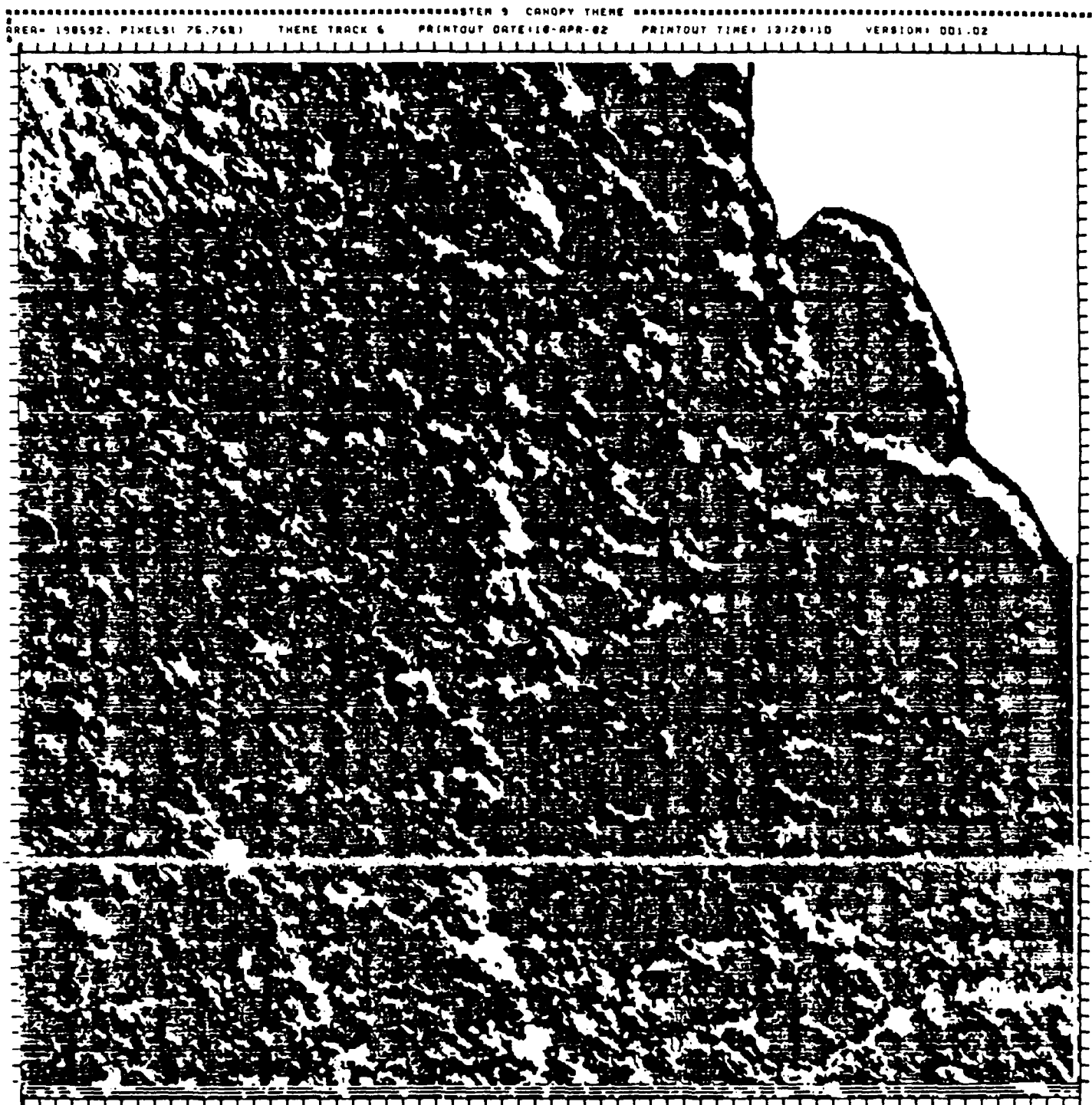


FIGURE 71

STEM 9 - Forest Canopy Theme

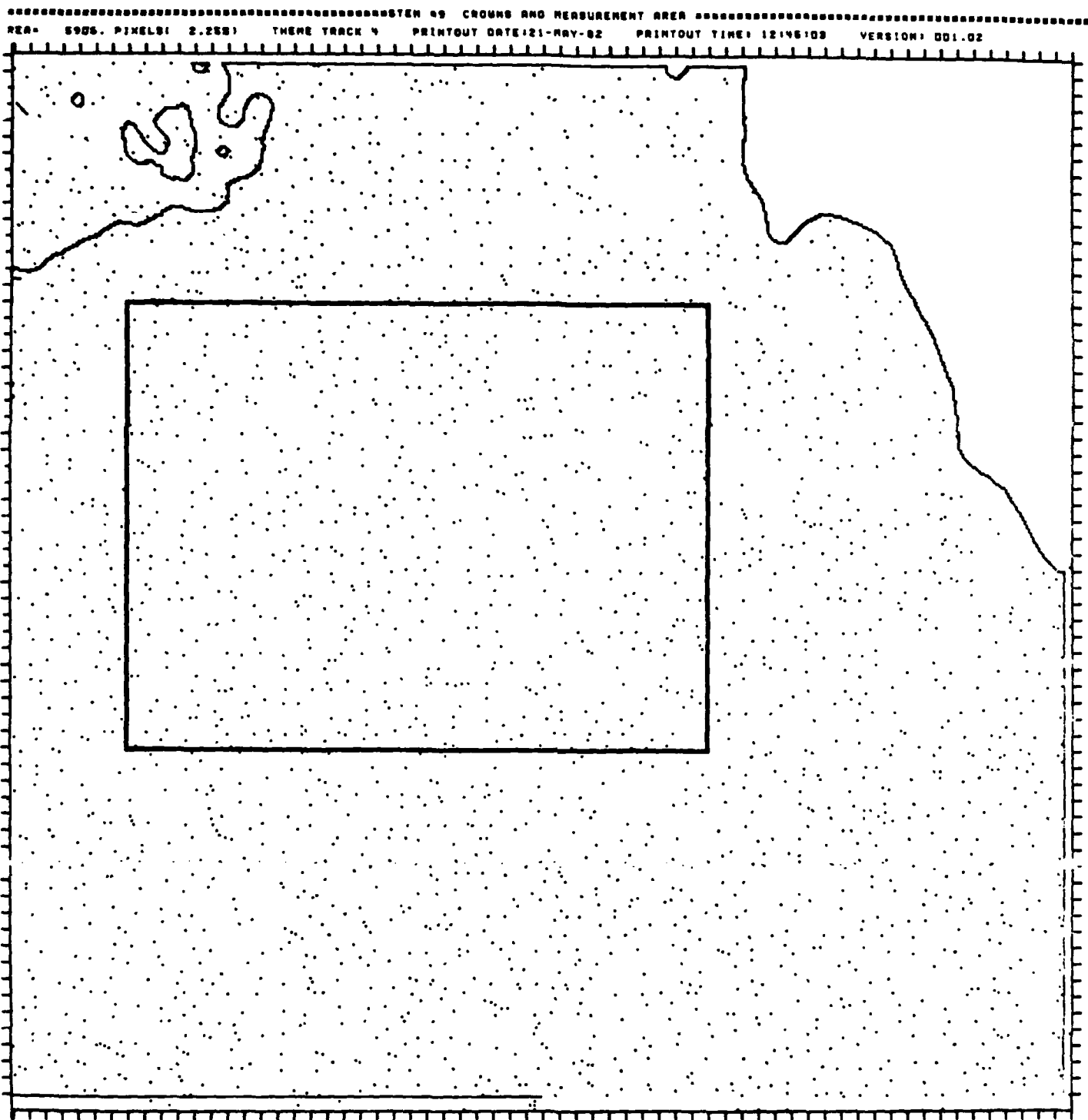


FIGURE 72

STEM 9 - Crown Location Theme

184 Stems/ha



FIGURE 73

STEM 9

CROWN LOCATIONS SUPERIMPOSED ON TREES

E. Stem 10 Processing Results

This area was digitized from a transparency the U.S. Forest Service has been using for photo interpretation training. The location of the image is unknown but is probably in a commercial logging area of the north-western portion of the USA. The transparency is an Ektachrome duplicate of color IR film. High contrast photographic processing, in combination with a relatively low solar elevation angle resulted in digital data with extreme contrast, and with exceptionally good tree crown definition. The trees in the area appear to be all pines, well separated in hilly terrain and covering about 50% of the ground. Sizes of individual crowns vary by a factor of three over the area digitized.

Categorization of the area was not performed as the test site was essentially all coniferous forest. A few small clearings might have been mapped properly as barren, but digital levels were saturated on the bright end of the density scale, making discrimination from bright trees difficult.

Crown location was easy and accurate for this site. The effectiveness of the crown template is directly related to crown definition, and this particular site with its extreme contrast and tree separation shows completely isolated crowns. In this situation the template worked well enough to locate crowns with widely ranging sizes in a single pass through the image, eliminating the usual multiple scale processing sequence. Visual assessment of crown locations indicates location accuracies of 90-100%. The only apparent errors occur at a few shadow boundaries in the small clearings.

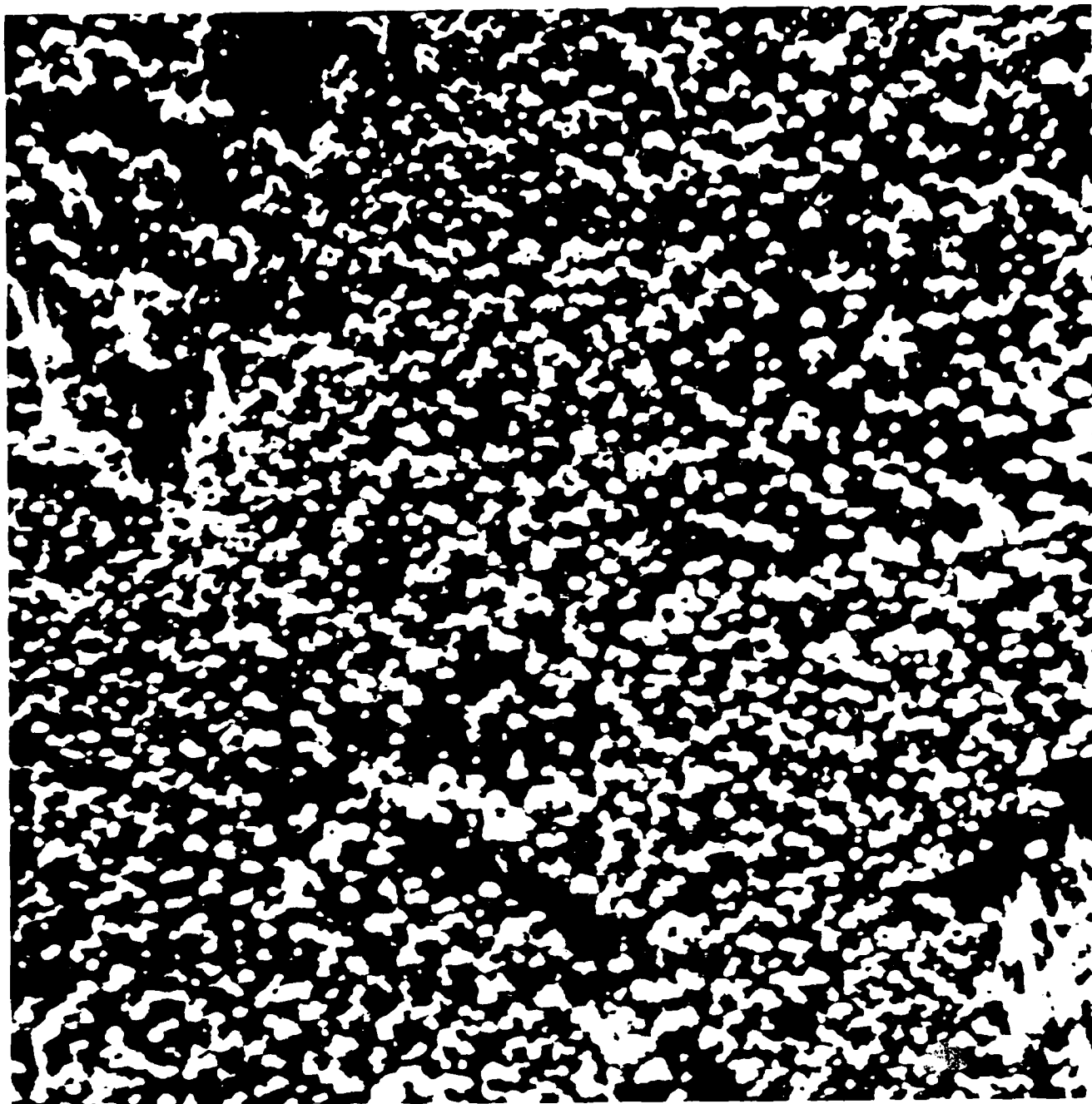


FIGURE 74

STEM 10 - Raw Data

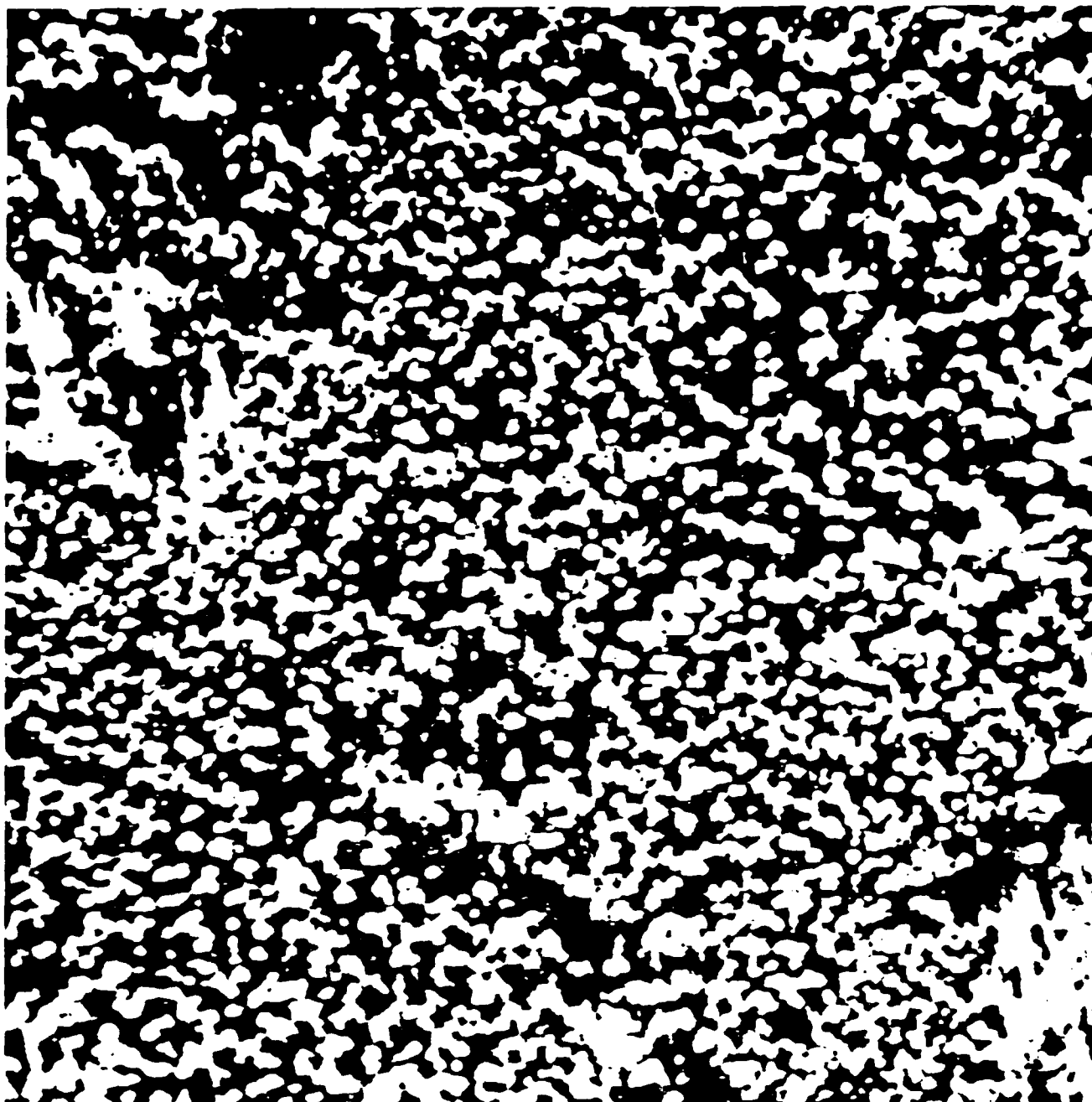
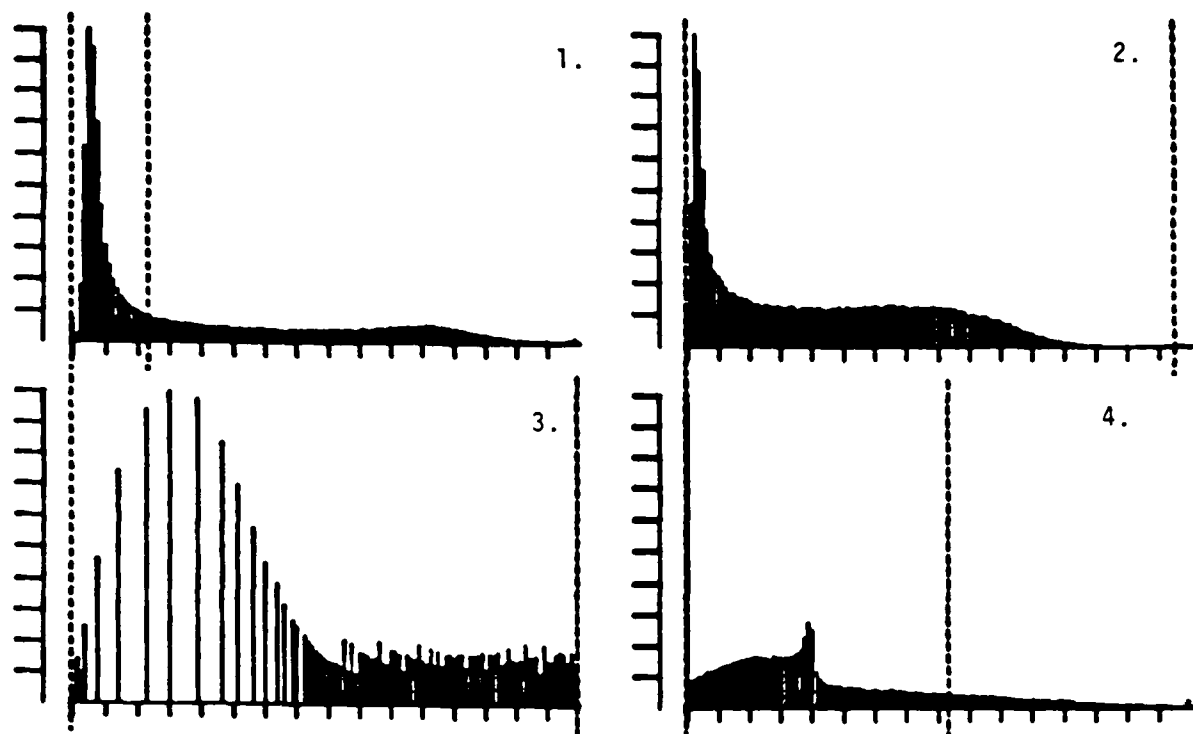


FIGURE 75

STEM 10 - Histogram Equalization Contrast Stretch



TRAINING SUMMARY 18-APR-82 19:49:07+
 8 LP UB DEL PEAK MEAN VAR +
 1 0 18 19 23018. 6.7 15.2 +
 2 0 123 124 16388 32.9 759.8 +
 3 0 127 128 11871. 64.7 1284.2 +
 4 0 66 67 24746 23.6 306.8 +
 TRAINING AREA=225391 PIXELS +
 ALARMED AREA=159230 PIXELS(60.7%) +
 TYPE CHS, (C)OMPARE, L(O)AD, E(X)IT

STEM 10
 1. RAW DATA WITH SHADOW THRESHOLD
 2. TEXTURE
 3. HISTOGRAM EQUALIZATION STRETCH
 4. CROWN TEMPLATE WITH THRESHOLD

FIGURE 76

STEM 10 - Key Histograms



FIGURE 77

STEM 10 - Tree Shadow Areas



FIGURE 78

STEM 10 - Forest Canopy Theme

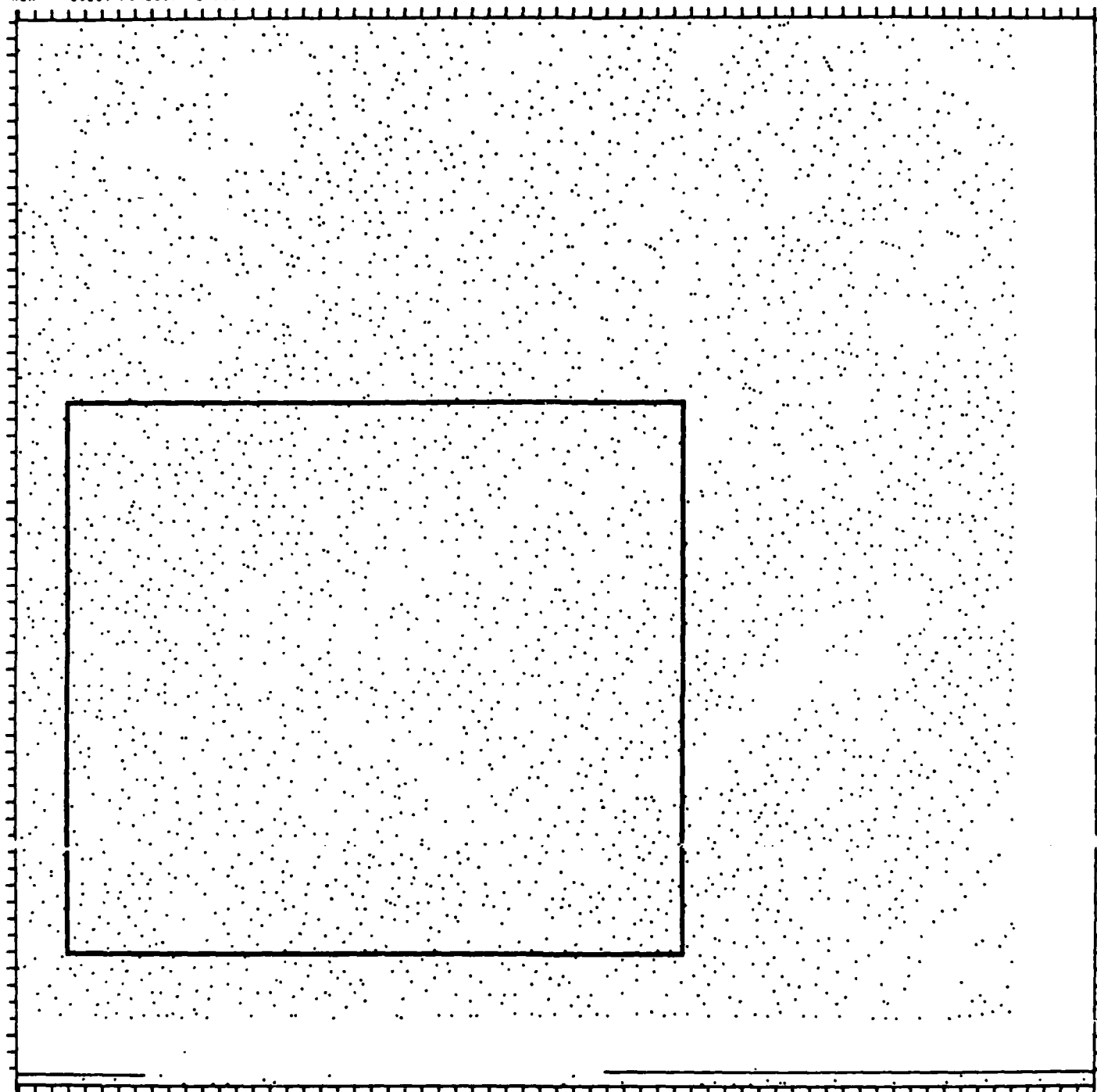


FIGURE 79

STEM 10 - Crown Location Theme
189 Stems/ha

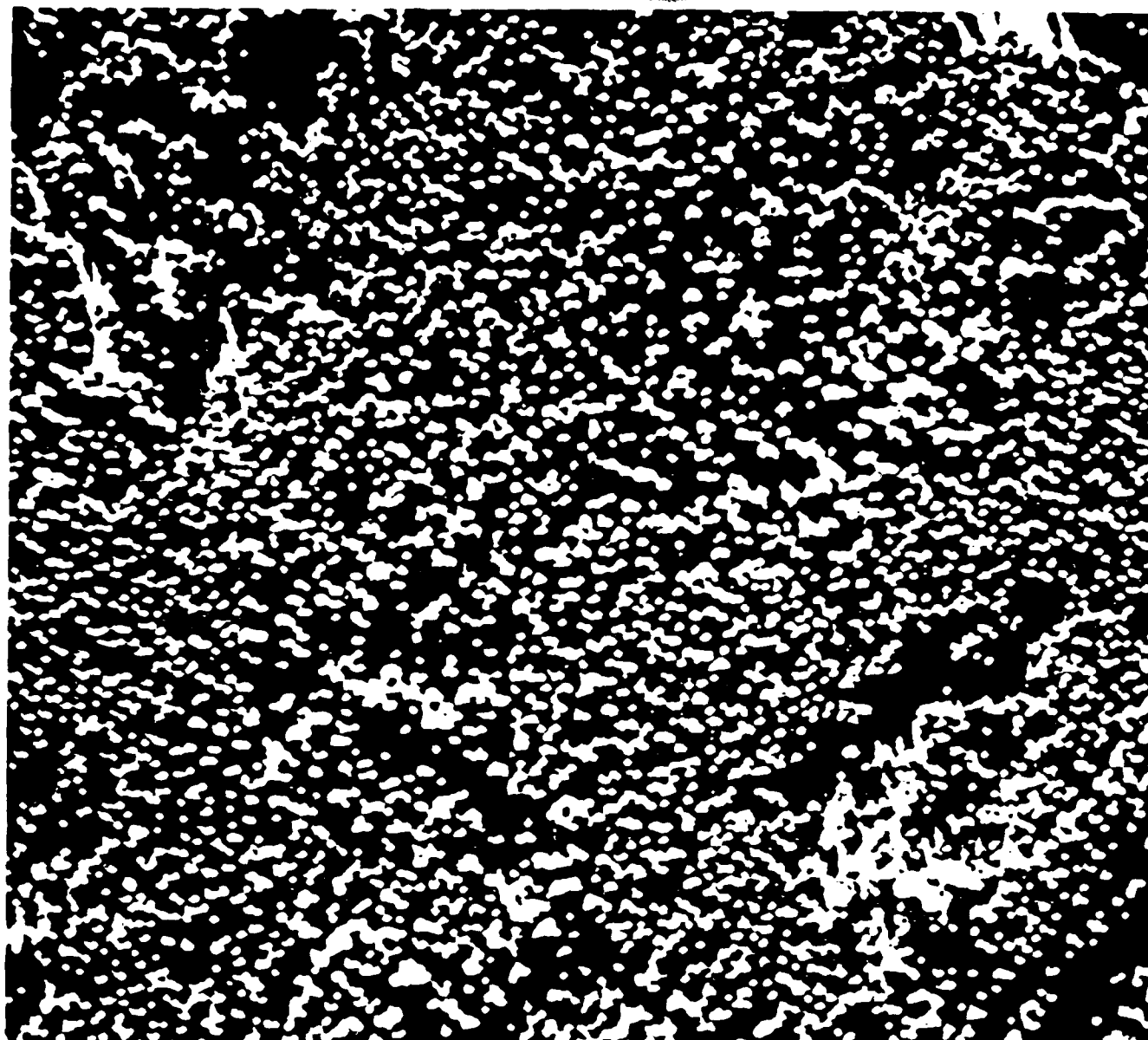


FIGURE 80

STEM 10

CROWN LOCATIONS SUPERIMPOSED ON TREES

F. Stem 13 Processing Results

The vegetation community covered by the stem 13 digitized area is very complex. Estimating from shadow lengths, trees range from over 100 ft. tall to small scrub. It also contained a fairly random mix of deciduous and coniferous trees. Either the size differences or the tree mix might be handled individually, but together they present a very difficult problem. Preliminary attempts to categorize the scene were not encouraging. In view of the scene complexity, and the fairly poor quality of the image, it was decided not to process this site.

G. Stem 14 Processing Results

This winter image was digitized from a panchromatic transparency and proved to be exceptionally easy to work with. The site contains two clearly defined forest stands, one pine and one deciduous.

Good coverage of a group of conifers in winter was the prime reason for selecting the site. The conifers are densely packed and the canopy appears fully closed. Individual crowns in the stand are better defined than in any of the closed canopy situations encountered on other test sites.

The alternate stand contains mature deciduous trees devoid of leaves. The stems of these trees are imaged as linear features radiating from the principal point of the photograph, appearing in high contrast against the forest floor. In the area digitized the stems are nearly parallel and are aligned with an 11 o'clock azimuth angle.

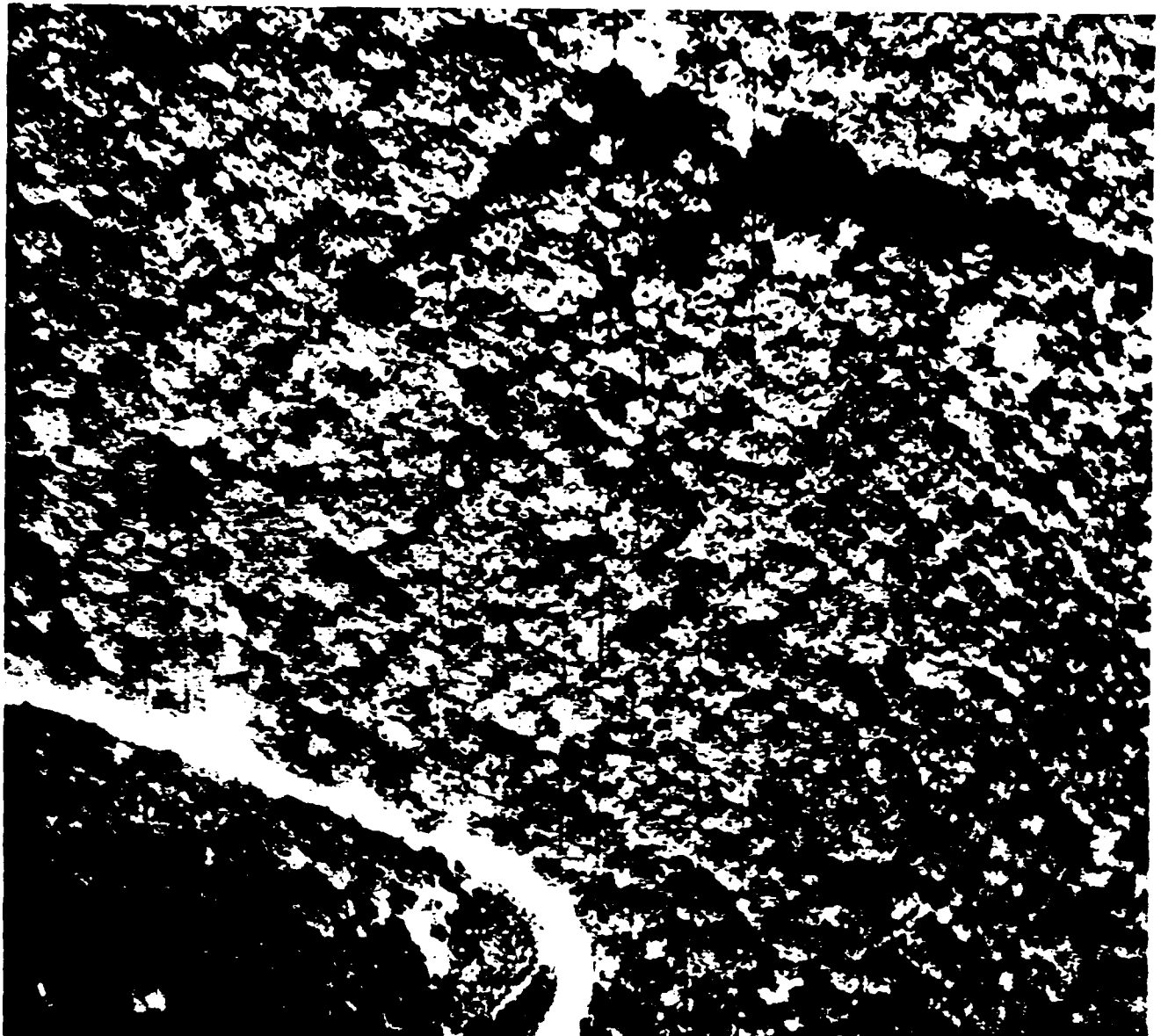


FIGURE 81

STEM 13

RAW DATA

Given the considerable difference in density between these two stands and a small unvegetated area, categorization of vegetation in the image was quite easy. This was the first image studied where textural information was not needed to discriminate between forest types. As with other sites a two dimensional classification procedure was used, but in this case the axes represented density vs. smoothed density.

Extraction of trees on this site was particularly effective. The good definition of crowns in the conifer stand allowed the circular crown template to locate individual trees in a very accurate manner. For the deciduous trees the circular crown template was clearly not appropriate so a 7x7 "line" template was used. Results were exceptionally good as the stems appear visually to have been located without significant error. The unique spatial properties of these trees facilitates their extraction. There are many errors in the resulting tree crown location theme but they result from problems in the blob counting algorithm, not from the technique.



FIGURE 82

STEM 14

RAW DATA

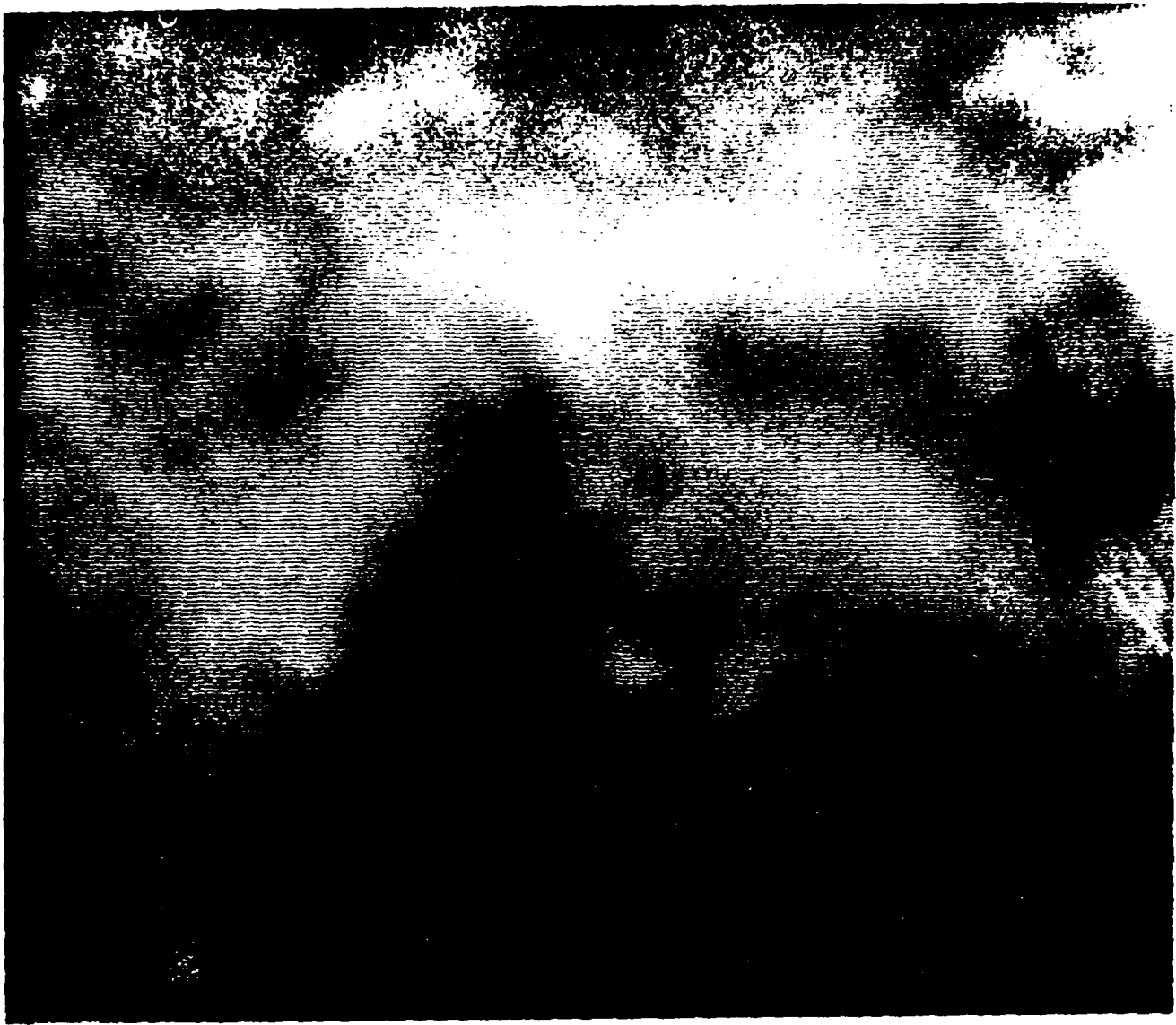
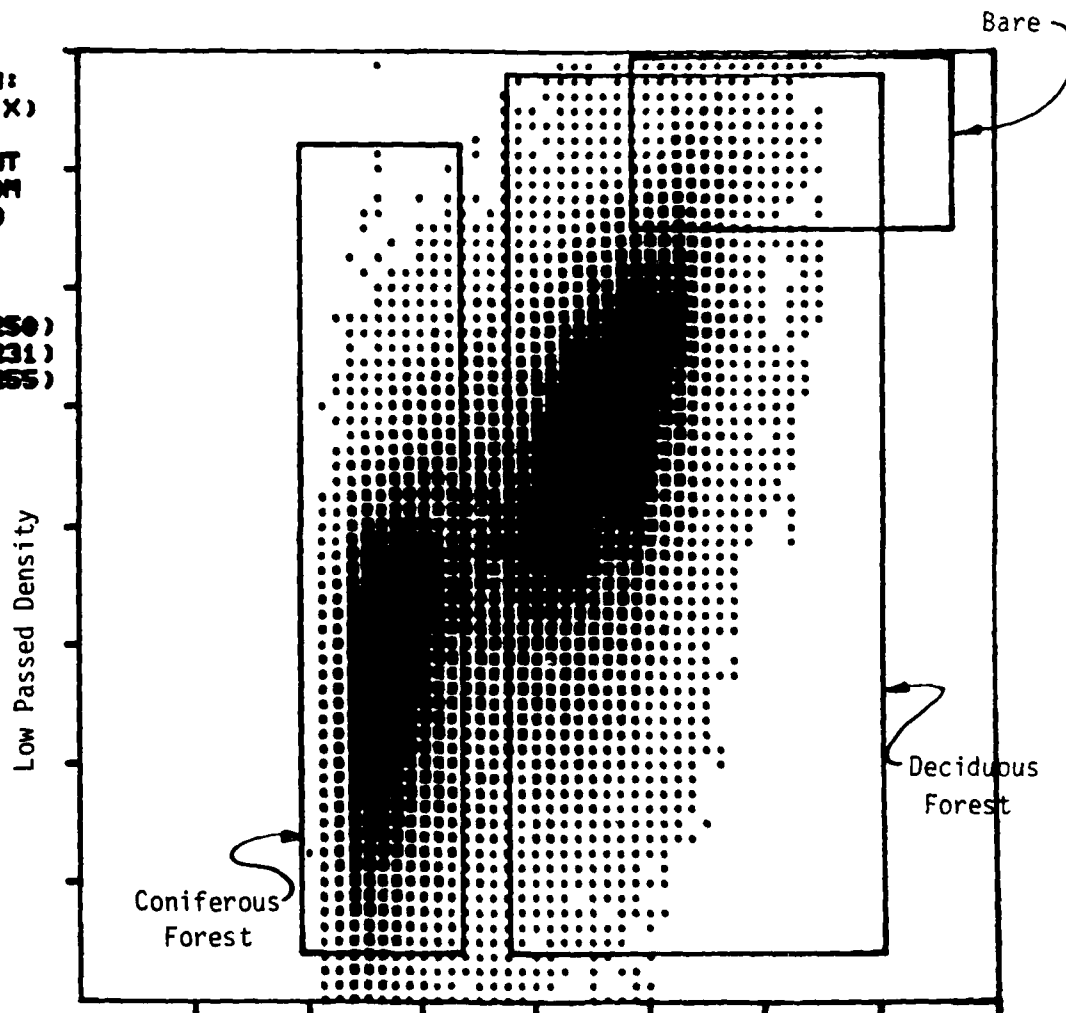


FIGURE 83
STEM 14
LOW PASSED DATA

2-D PROJECTION:
CH2(Y) VS CH4(X)

(L)EFT, (R)IGHT
(T)OP, (B)OTTOM
(D)RAW, L(O)AD

(121-226, 13-250)
(62-108, 13-231)
(156-245, 208-255)



Stem 14 Vegetation Signatures

FIGURE 84

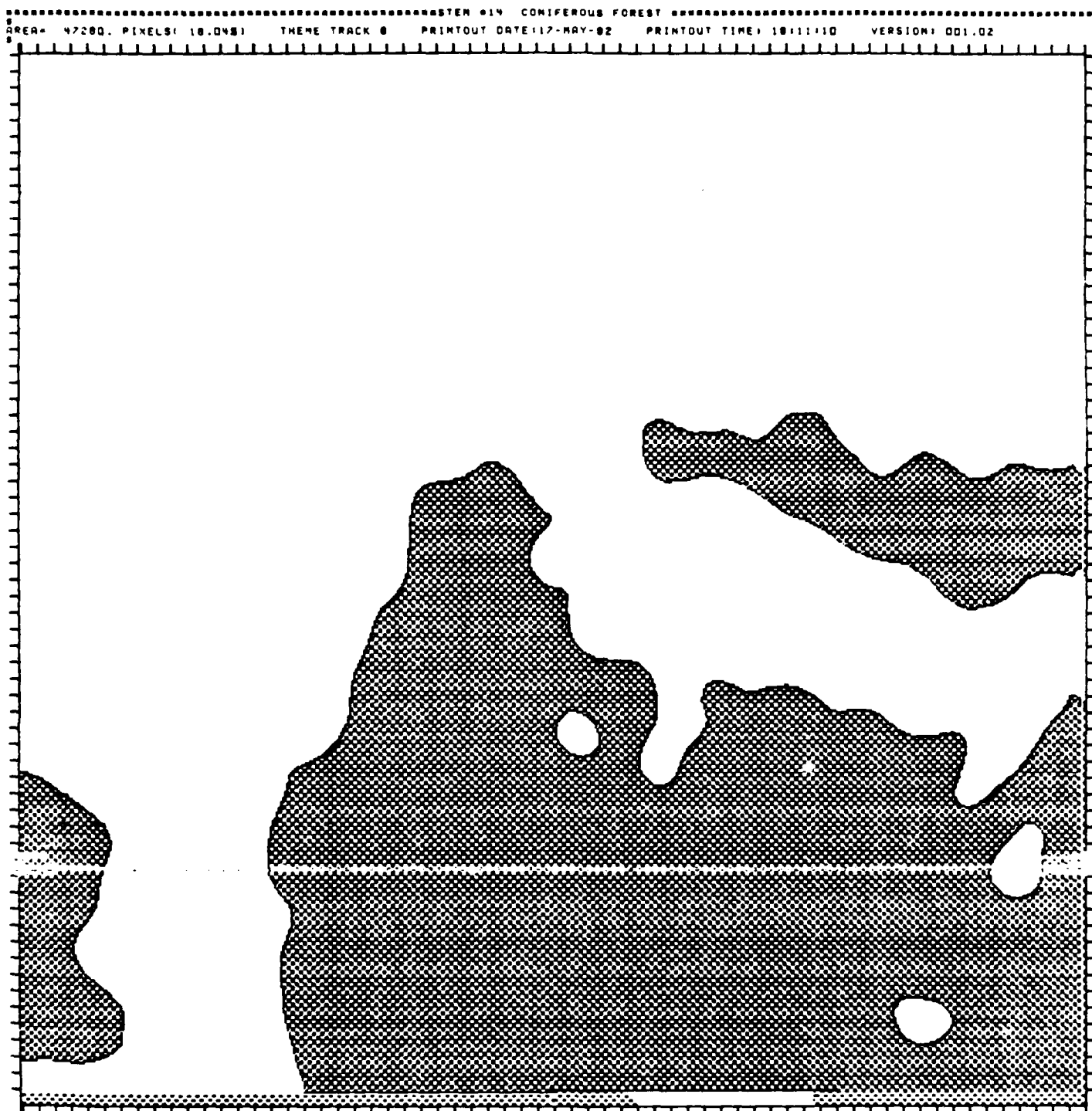


FIGURE 85

Stem 14 Deciduous Forest

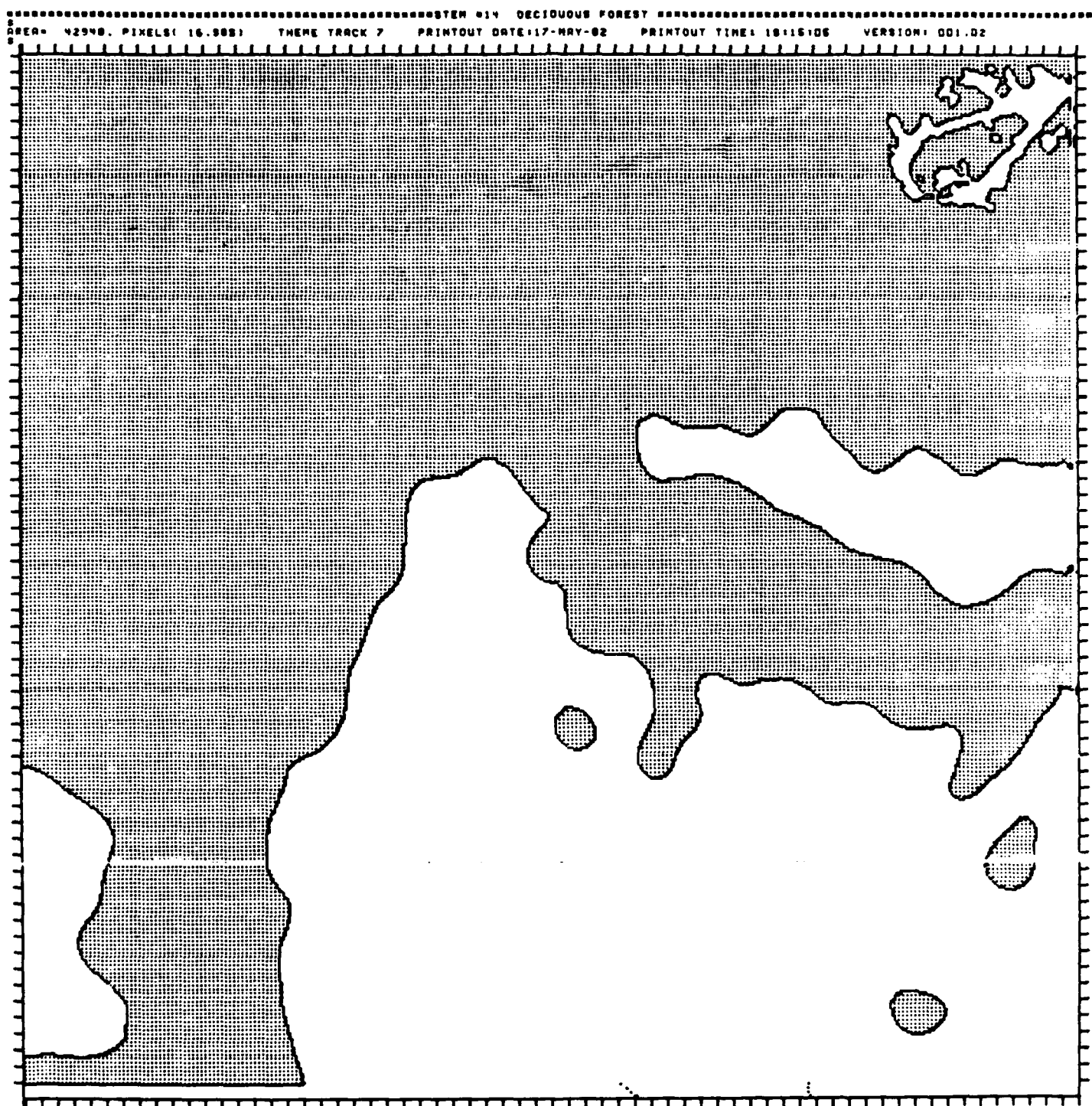
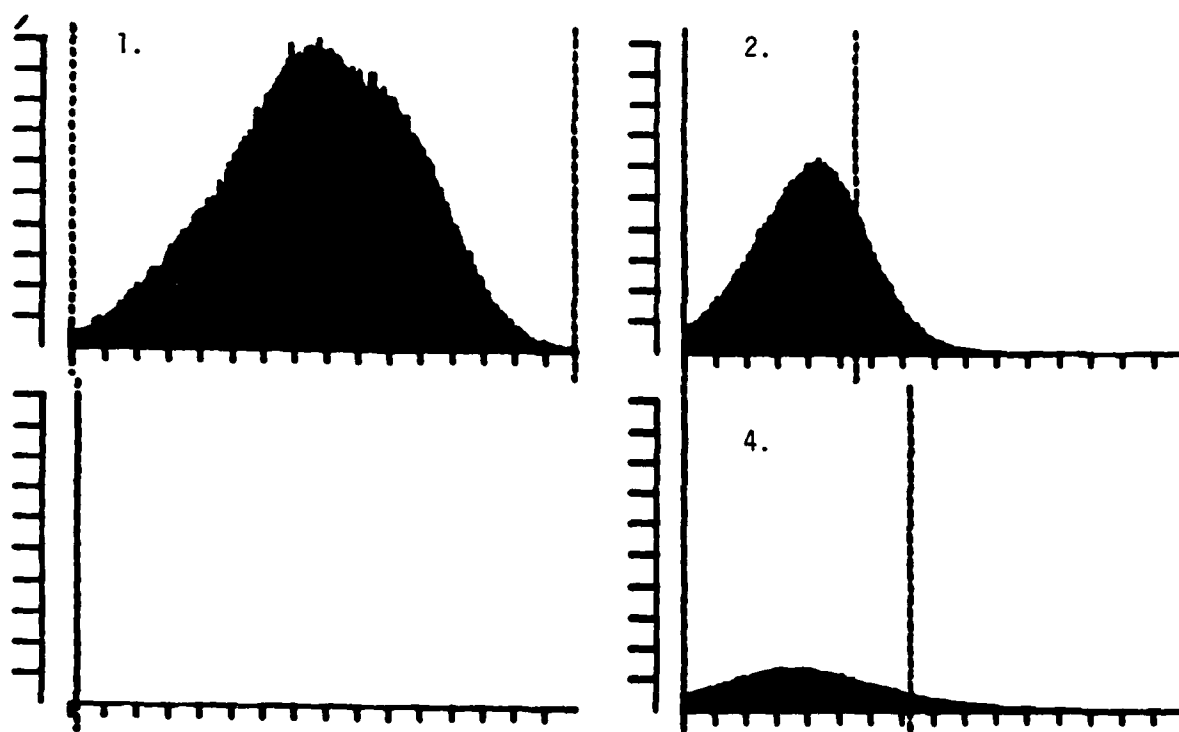


FIGURE 86

Stem 14 Coniferous Forest



TRAINING SUMMARY 17-MAY-82 18:17:05+
 8 LB UB DEL PEAK MEAN UAR +
 1 0 255 256 1505. 124.42157.7 +
 2 0 88 89 4237. 54.0 518.2 +
 3 3 3 1 52076. 3.0 0.0 +
 4 0 116 117 13238. 53.71022.2 +
 TRAINING AREA=183148. PIXELS +
 ALARMED AREA=177173. PIXELS(97.8X) +
 TYPE CHS, (C)OMPARE, L(O)AD, E(X)IT+

STEP 14
 1. RAW DATA
 2. GROW TEMPLATE
 ?
 4. STEP TEMPLATE

FIGURE 87

Step 14 Key Histograms

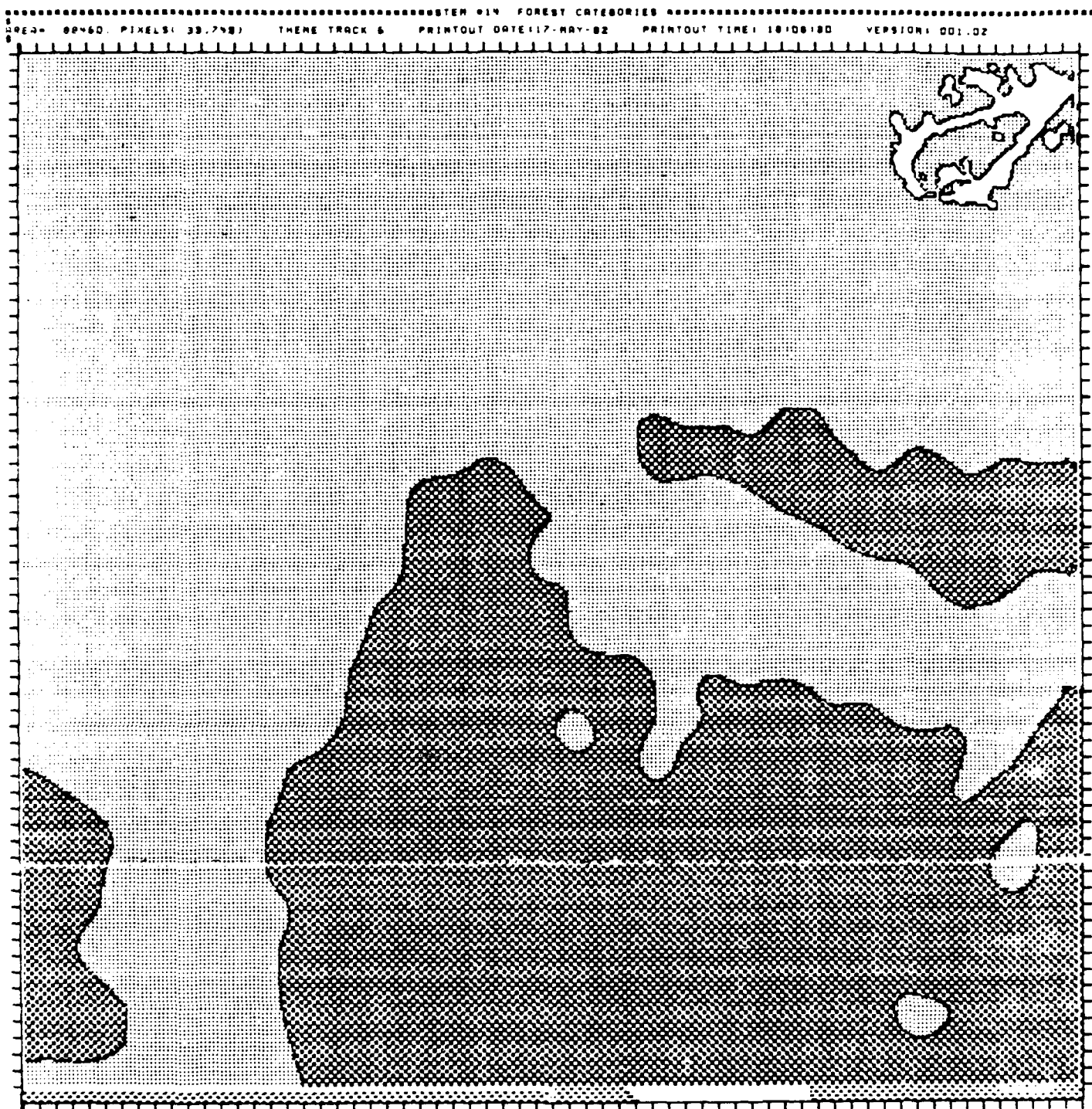


FIGURE 88

Stem 14 Vegetation Categories

	-3	-2	-1	0	1	2	3
3	0.000	0.250	-0.750	0.125	0.125	0.125	0.000
2	0.125	0.125	0.125	-0.750	0.125	0.125	0.250
1	0.125	0.125	0.125	-0.750	0.125	0.125	0.125
0	0.125	0.125	0.125	-0.750	0.125	0.125	0.125
-1	0.125	0.125	0.125	-0.750	0.125	0.125	0.125
-2	0.250	0.125	0.125	-0.750	0.125	0.125	0.125
-3	0.000	0.125	0.125	0.125	-0.750	0.250	0.000

45 NON-ZERO ELEMENTS, -3 TO 3 IN X, -3 TO 3 IN Y
 SUM OF ELEMENTS = 0.000
 OUTPUT OFFSET = 63

CR OR MENU OPTION >

FIGURE 89

Stem 14 Template for Bare Stems
 Oriented at 11 O'clock

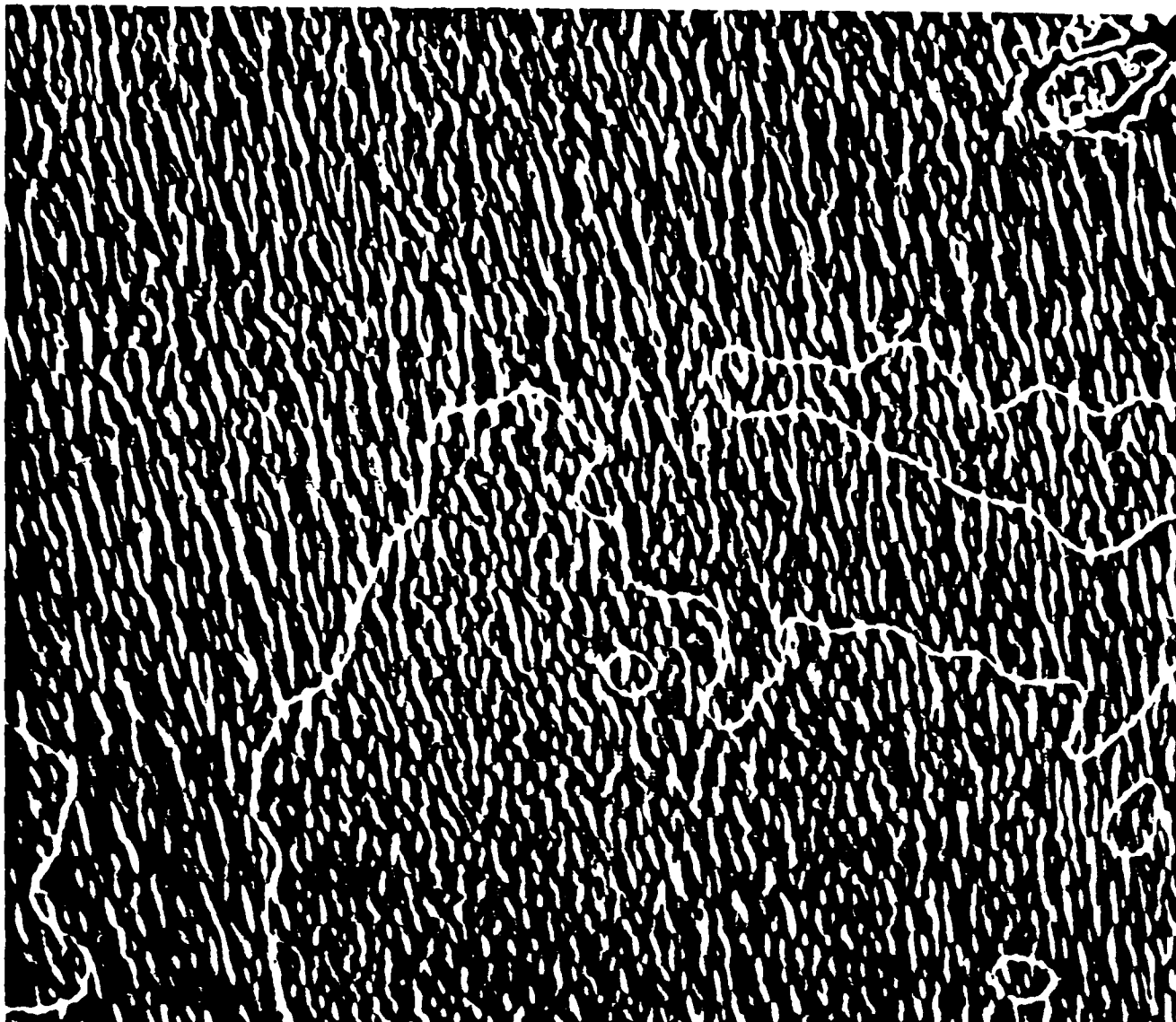


FIGURE 90

STEM 14

STEM TEMPLATE OUTPUT

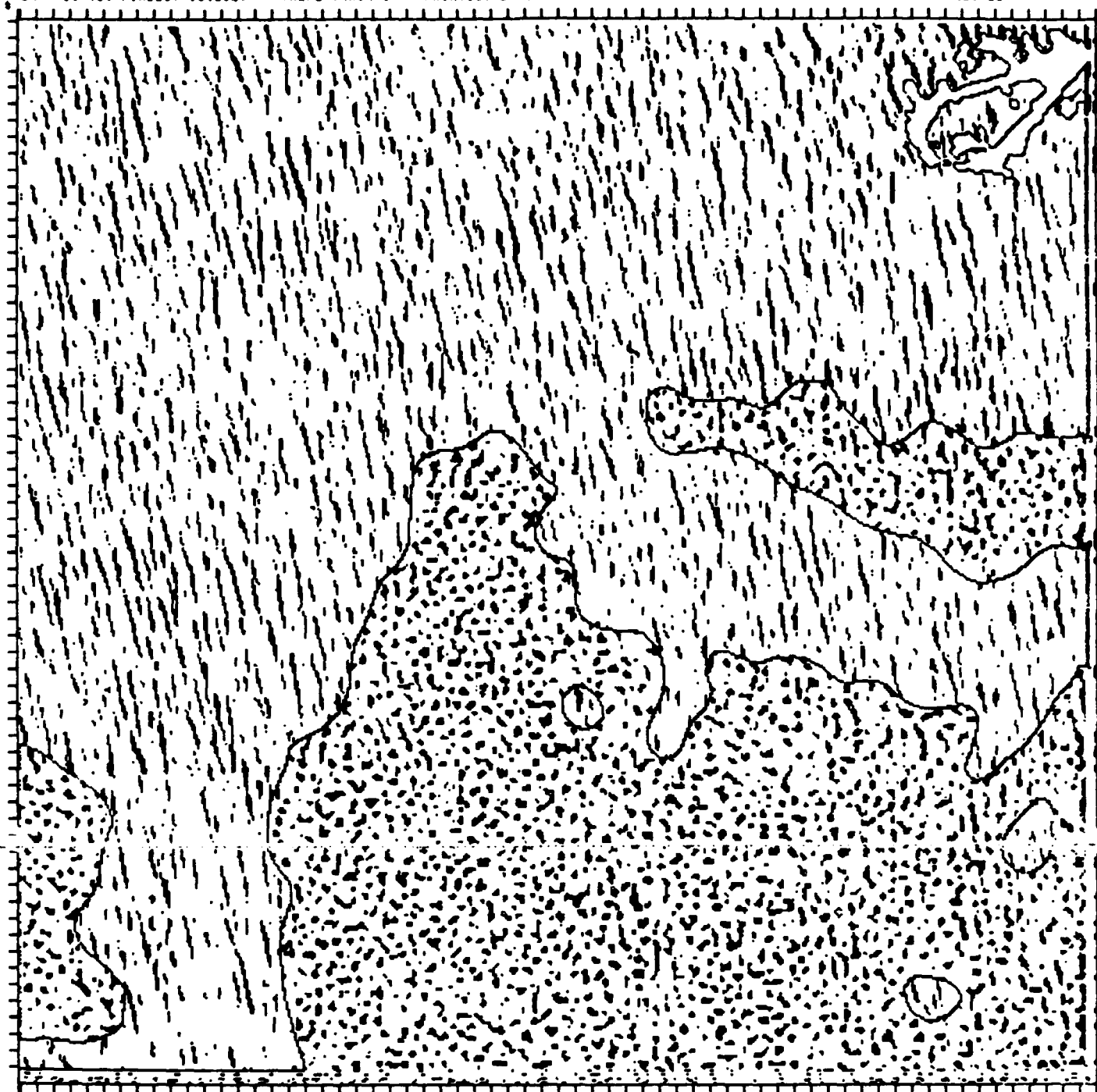


FIGURE 91

Stem 14 Slices From Crown and Stem Templates

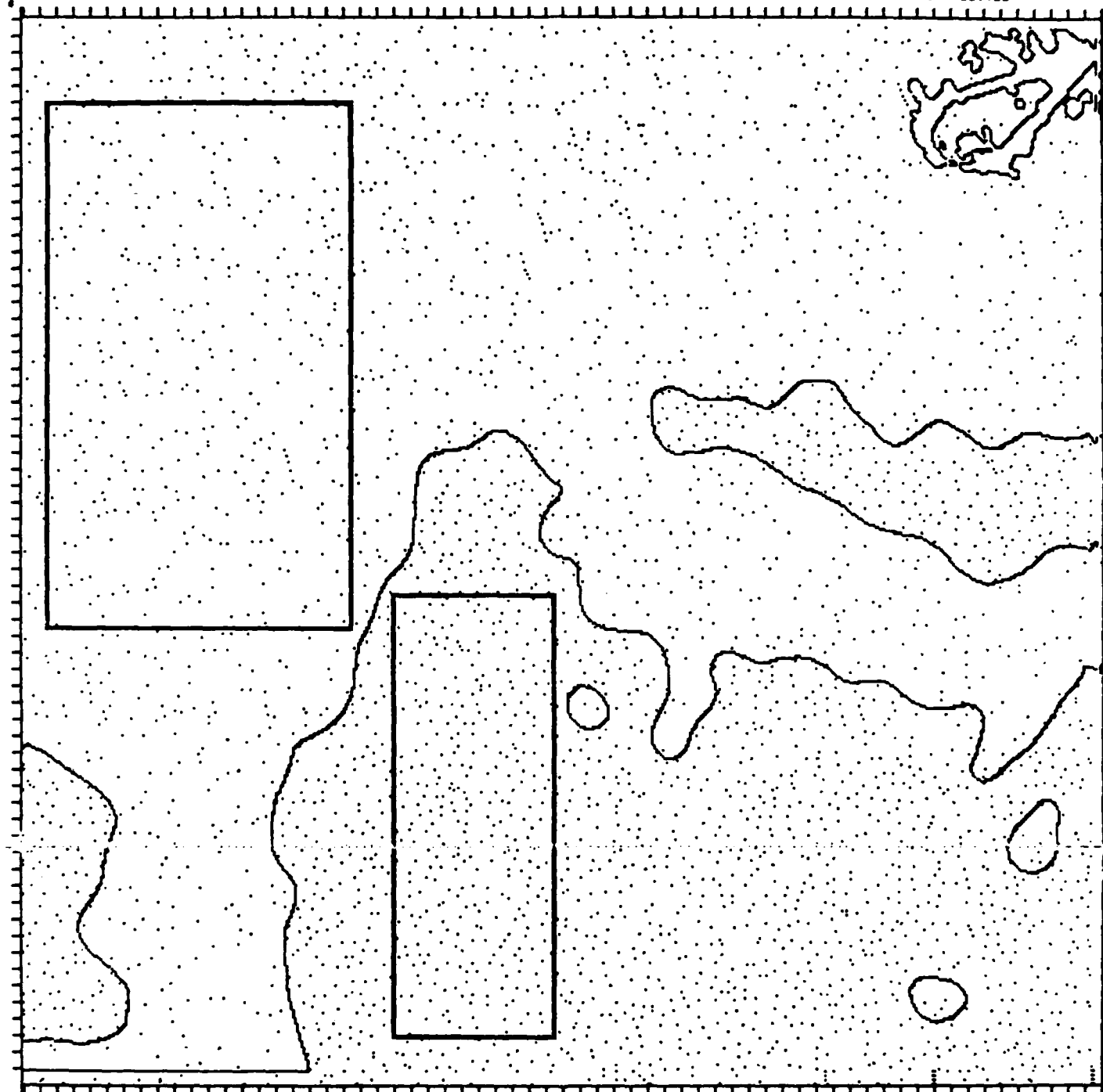


FIGURE 92

Stem 14 Crown Location Theme

Coniferous Area 600 Stems/ha

Deciduous Area 269 Stems/ha

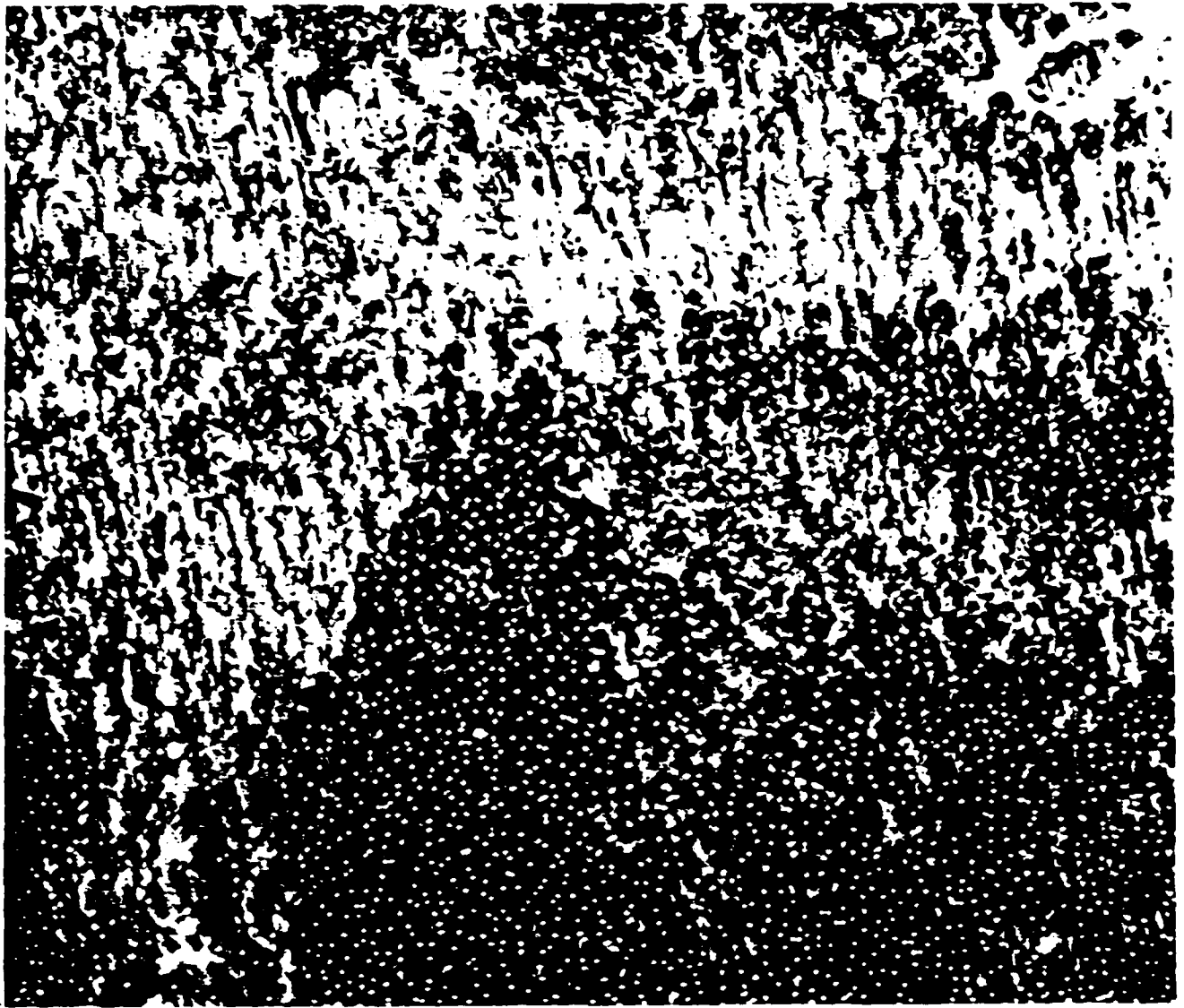


FIGURE 93

STEM 14

CROWN LOCATIONS SUPERIMPOSED ON TREES

H. Stem 15 Processing Results

This is a winter image digitized from panchromatic transparency. It is of particular interest as it covers the same area (ground truth site A) as does the stem 7 summer image. The two primary forest stands in the image are far better defined than in the summer image as the deciduous trees are without foilage.

Categorization of the vegetation classes was not difficult, but was accomplished in a manner different from other sites. The five pixel textural operator was used on initial efforts and while it easily separated the grassland areas, it was not especially good for distinguishing the forest types. Both types are characterized by a high local variance. Classes were ultimately extracted from space defined by smoothed density and smoothed texture. A minor amount of theme filtering was then used to clean up the categories.

The bare tree stems were located by applying the same template used in the stem 14 data set, a 7x7 pixel dark line detector aligned with the apparent direction of the tree stems. Again the extraction of stems appeared to be near perfect under visual inspection, but on a few stems the "blob counting method" malfunctioned, resulting in multiple counting of these stems.



FIGURE 94

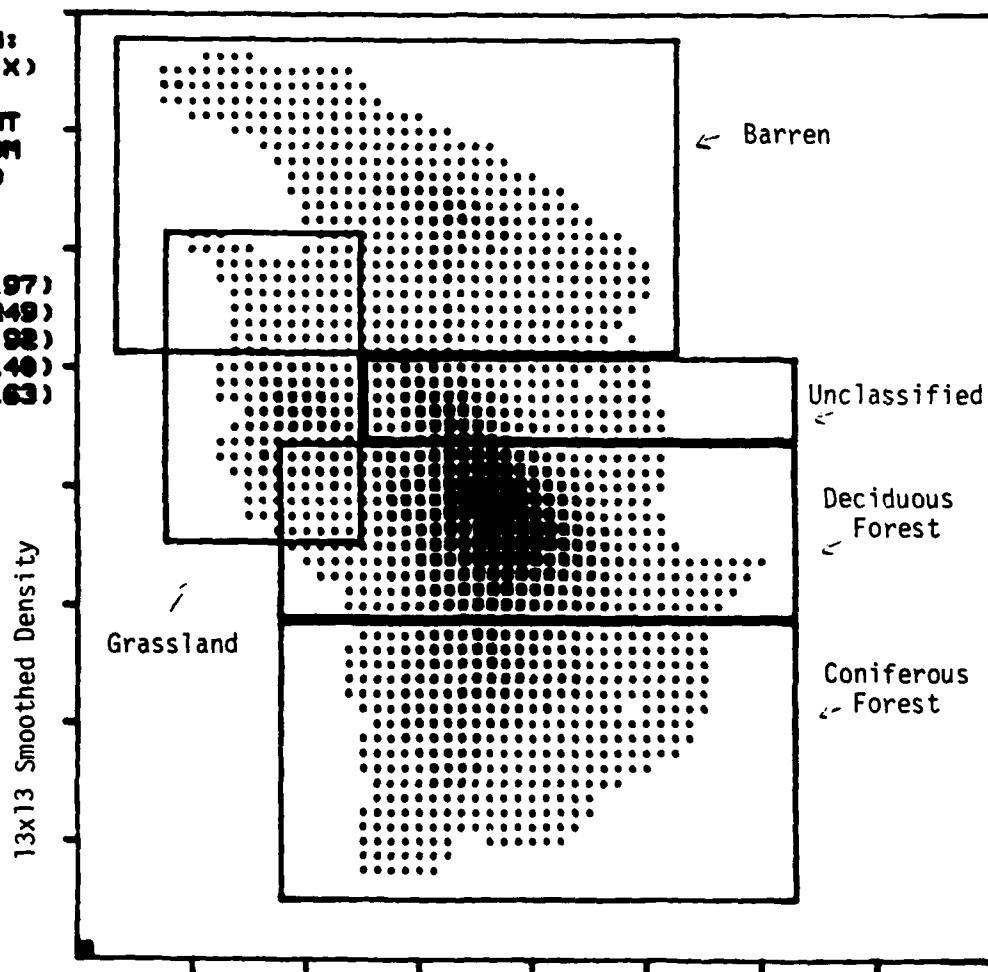
STEM 15

RAW DATA

PROJECTION:
 (M)EIV, (U)S CH4(X)

(L)EFT, (R)IGHT
 (T)OP, (B)OTTOM
 (D)RAW, L(O)AD

(25- 83, 113-197)
 (11-169, 164-249)
 (57-202, 16- 92)
 (57-202, 93-140)
 (81-202, 141-163)



11 x 11 Smoothed Texture

FIGURE 95

STEM 15 - Vegetation Signatures

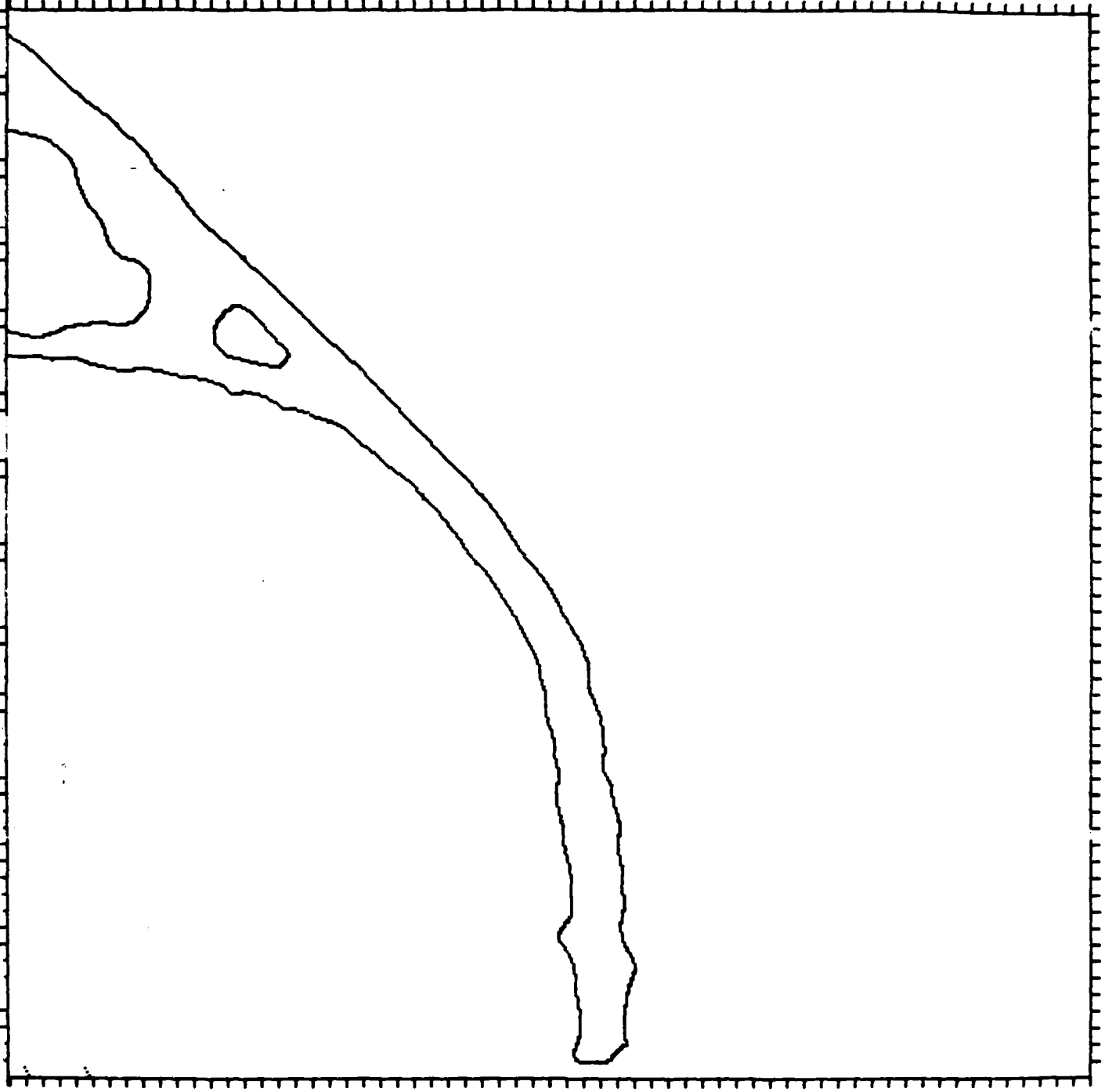


FIGURE 96
STEM 15 - Barren



FIGURE 97

STEM 15 - Grassland

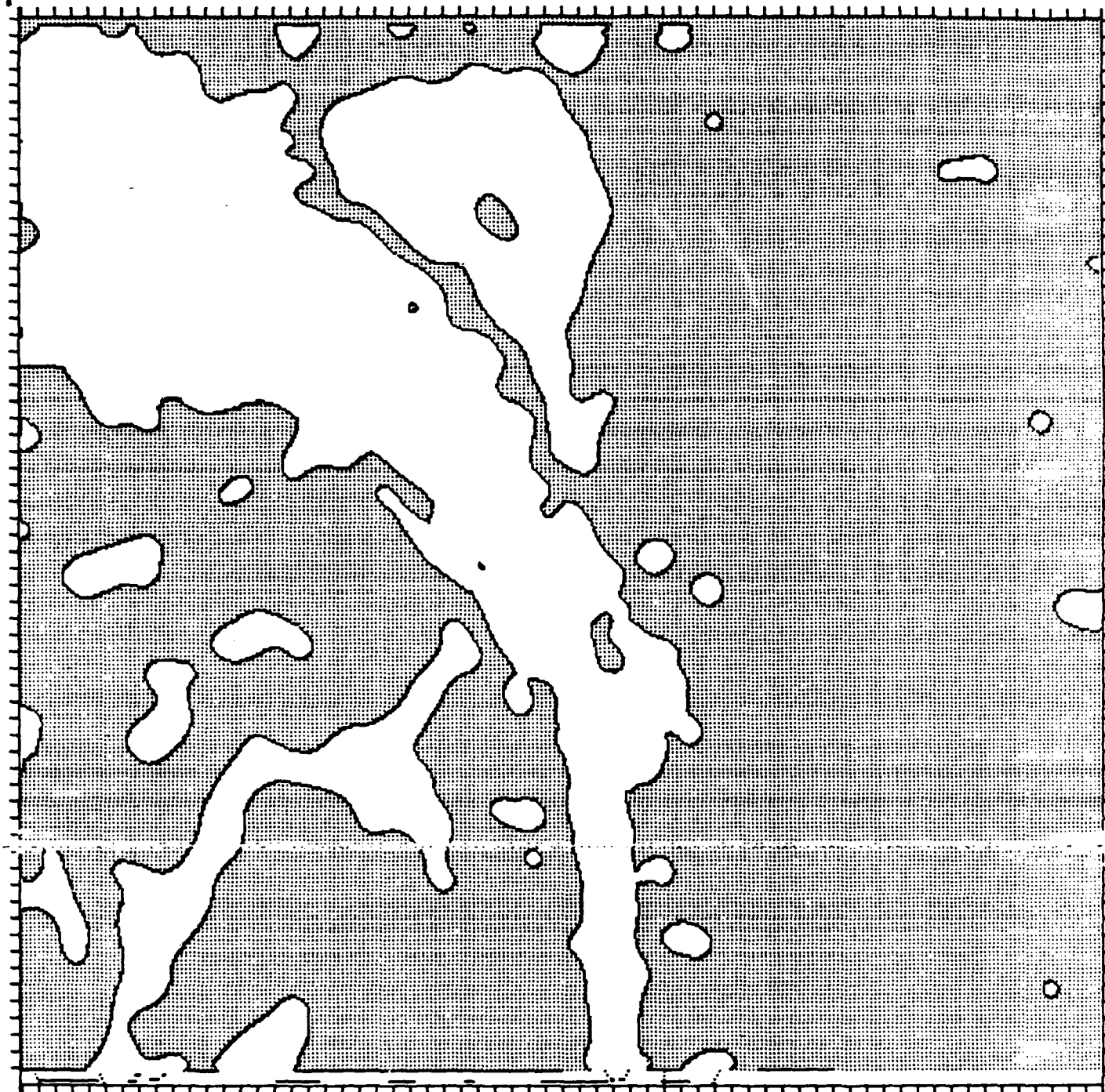


FIGURE 98

STEM 15 - Deciduous Forest

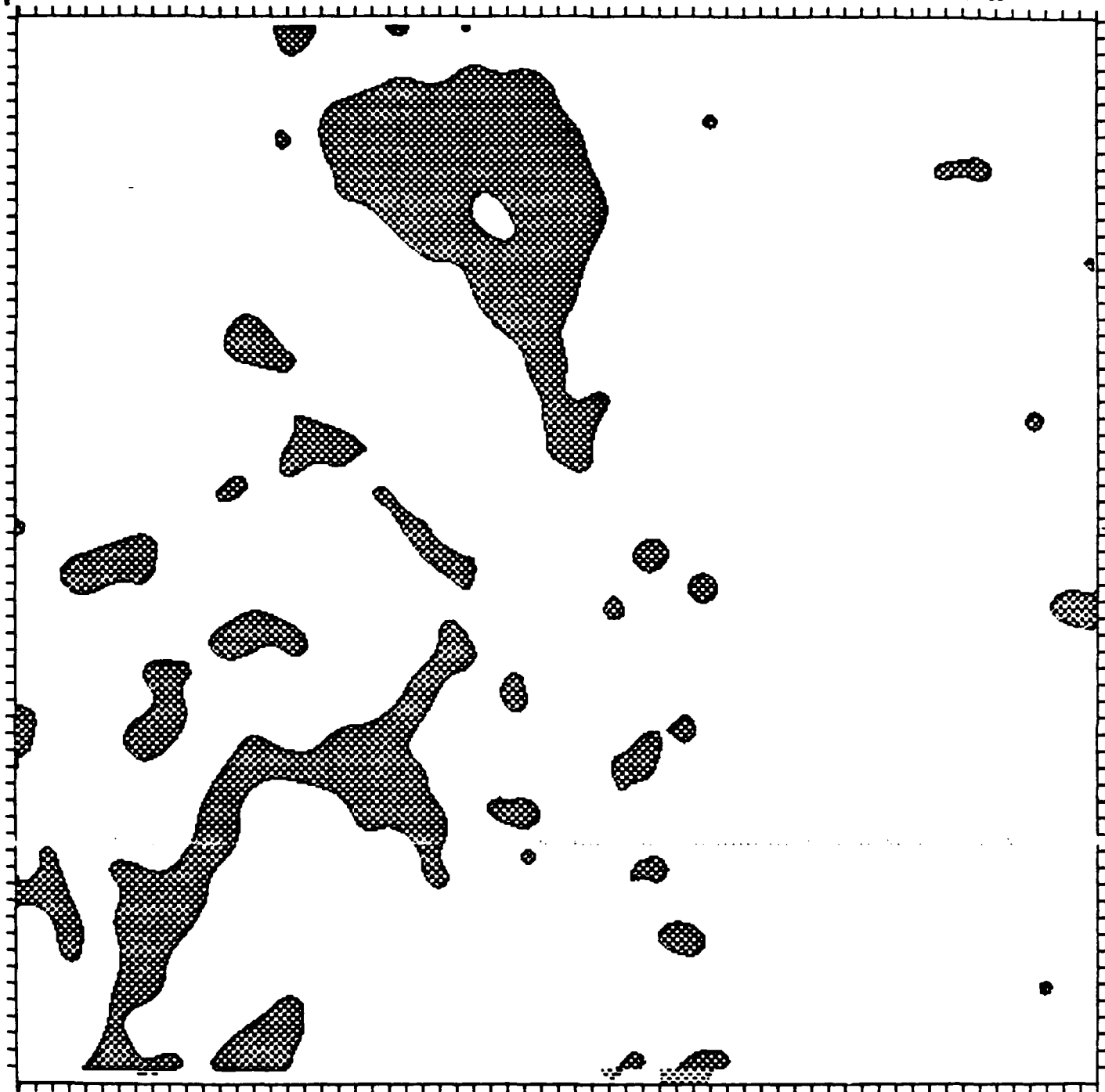


FIGURE 99

STEM 15 - Coniferous Forest

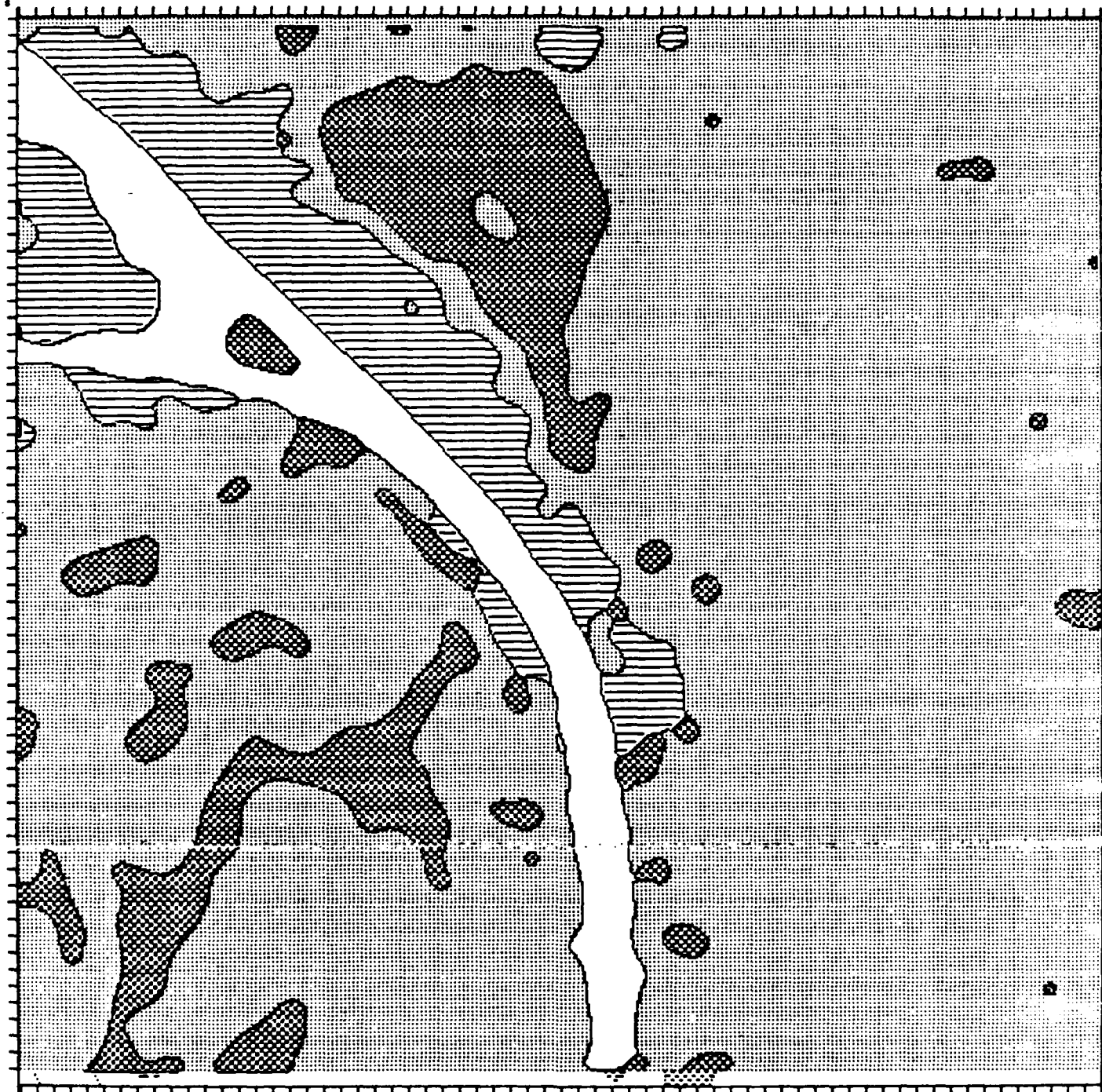


FIGURE 100

STEM 15 - Vegetation Categories

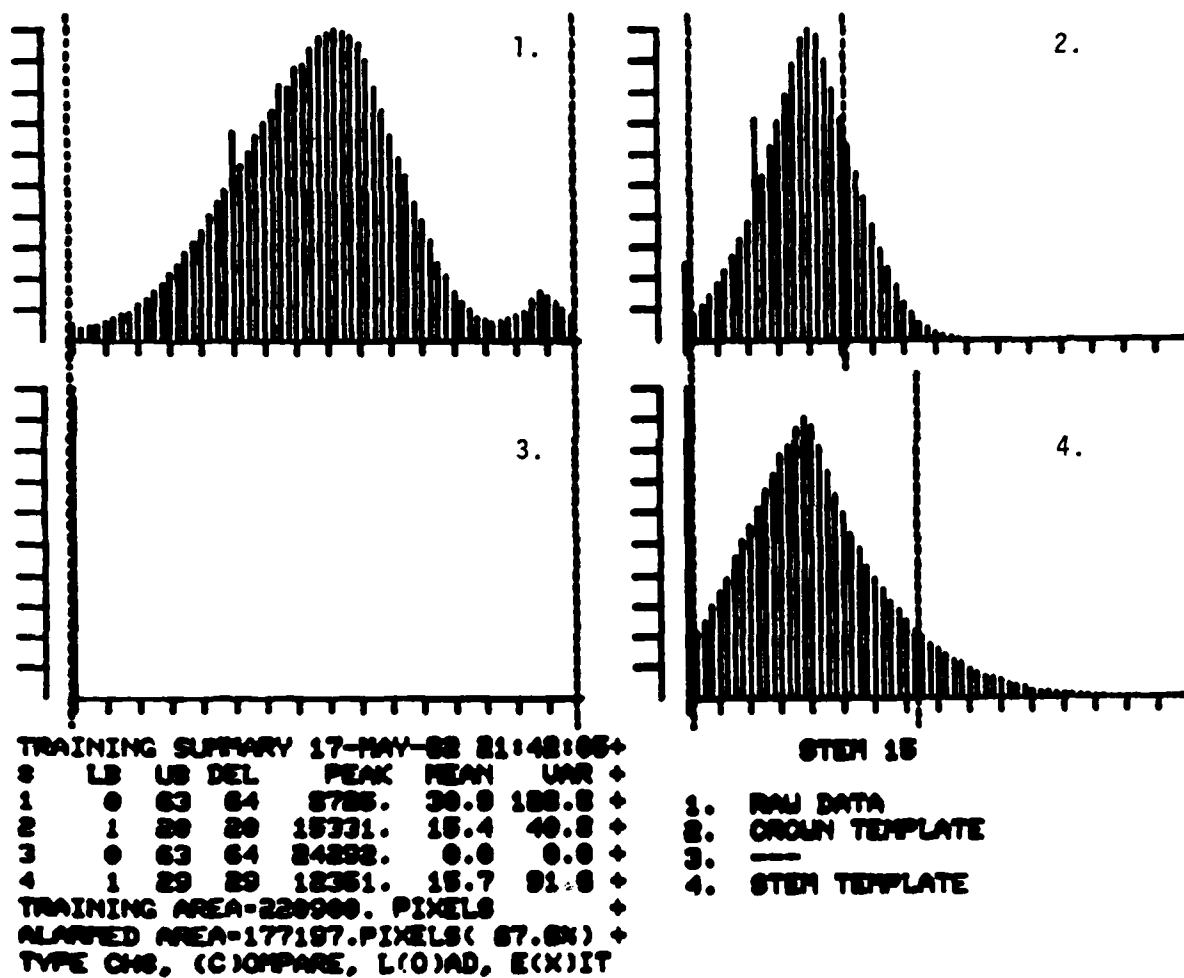


FIGURE 101

STEM 15 - Key Histograms

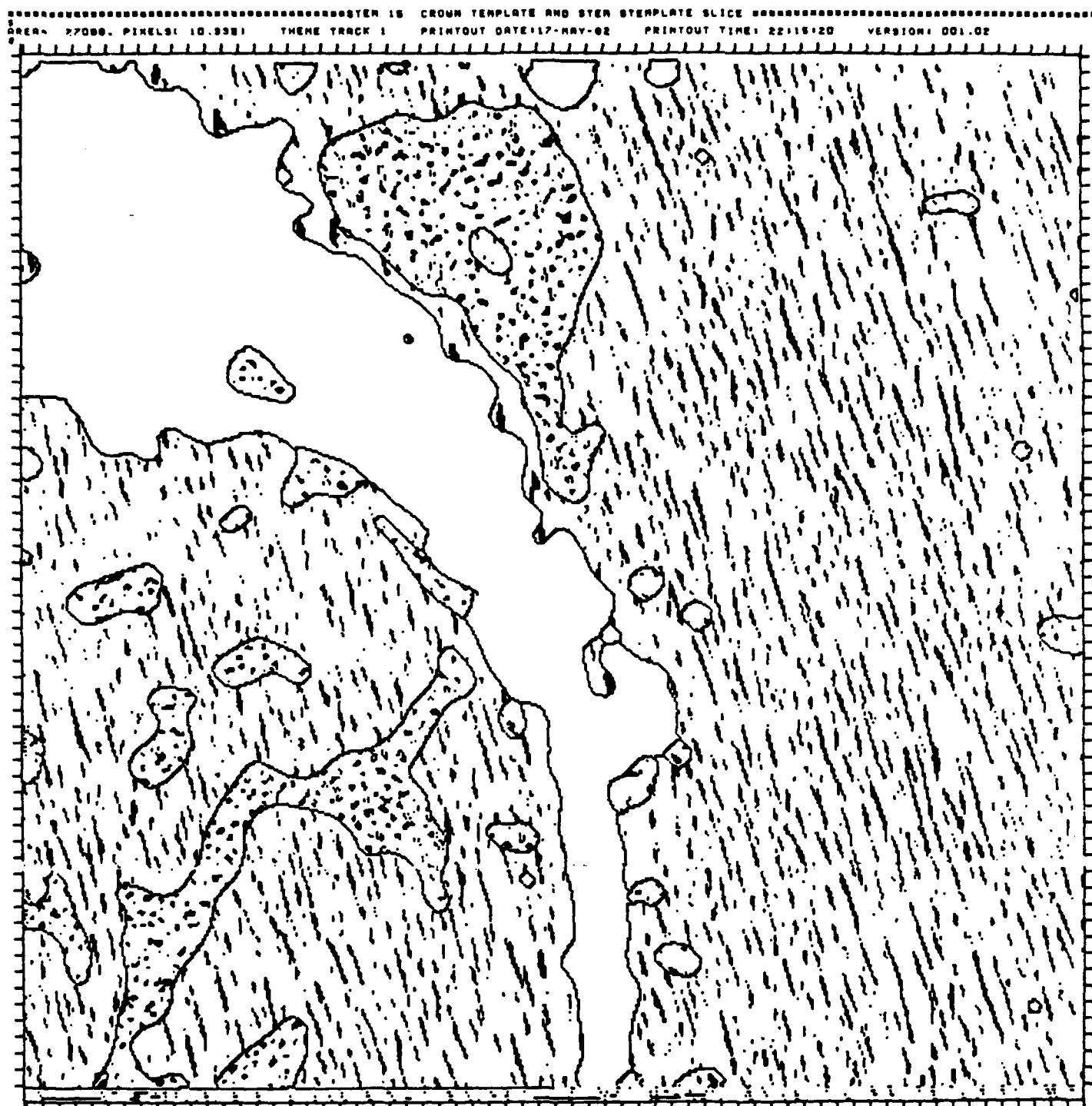


FIGURE 102

STEM 15 - Slices From Crown And Stem Templates

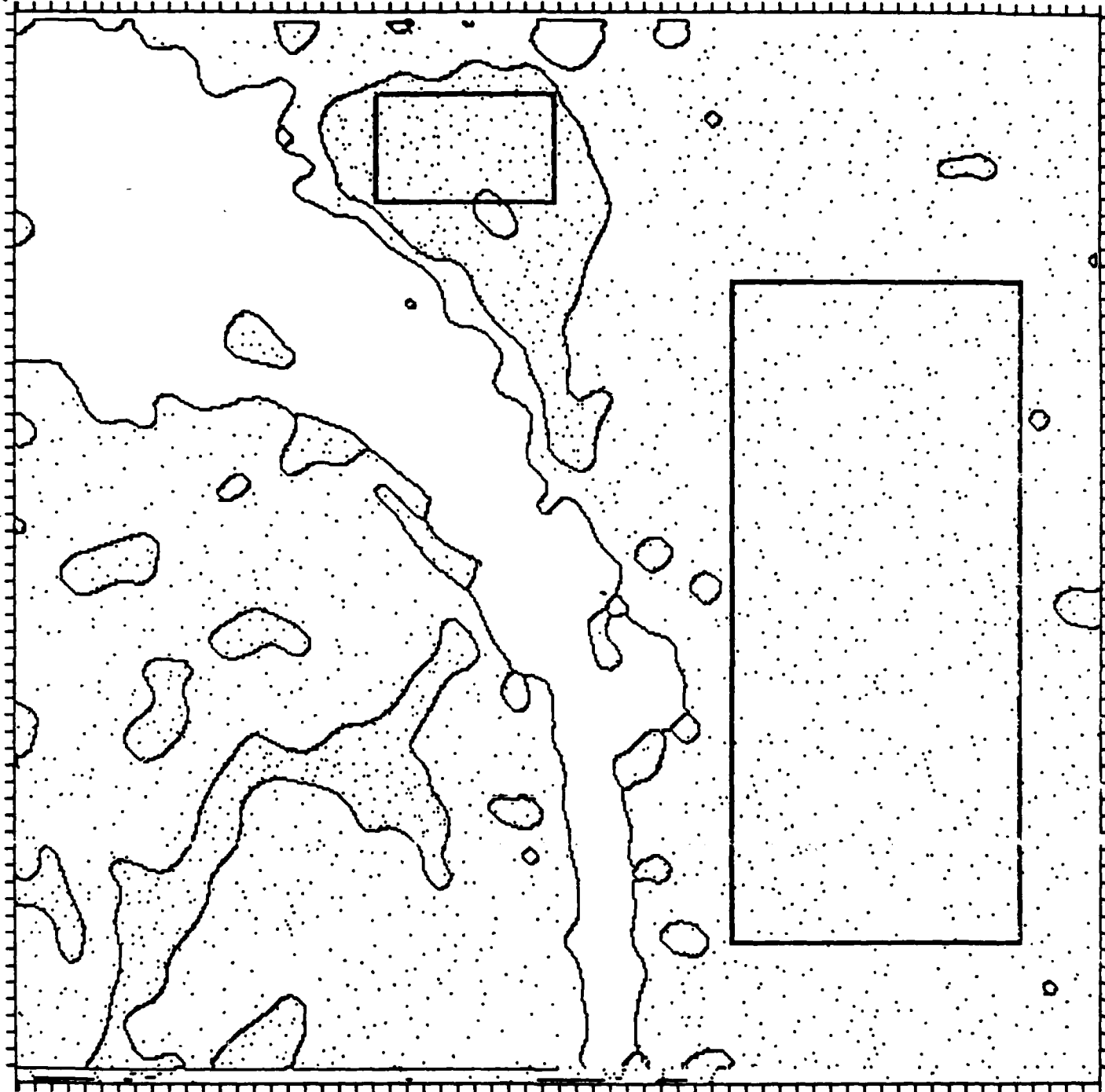


FIGURE 103

STEM 15 - Crown Location Theme

Coniferous Area 562 stems/ha

Deciduous Area 276 stems/ha

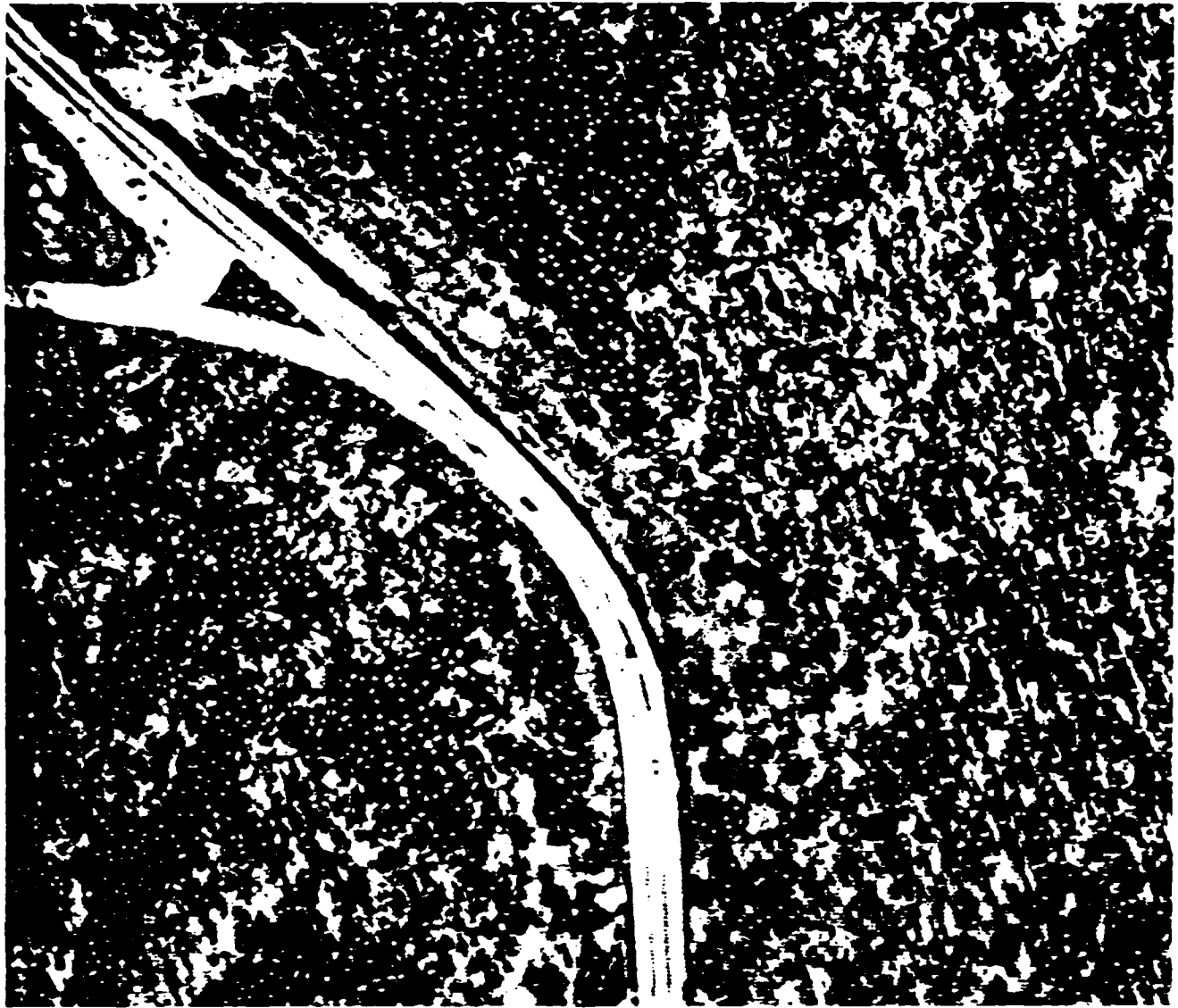


FIGURE 104

STEM 15

CROWN LOCATIONS SUPERIMPOSED ON TREES

V. Comparison of Processing Results and Data Collection

The primary means of verifying digital processing results, and of determining accuracy and utility of digital measurements was by in field data collection. For the test sites designated A through D, all located in the Fort Belvoir Hunting Area, investigation crews were sent into the field to collect detailed information concerning species, stem densities and stem diameters. For each of the ground truth sites, measurements were made on several small sample plots arranged to describe a typical transect through the site. Within the sample plots, each 1/10 of an acre in size, a cord was attached to a tree and used to define the arc of a circle .1 acre in area. All trees with stem diameters greater than ten centimeters encircled by the arc were recorded.

The ground data were reduced by separating the sample plots into groups which coincided with relatively uniform forests stands which could be located on the imagery. Five to ten plots were associated with each forest stand allowing a mean and standard deviation to be computed.

For the collection site designated "Pine 1" stem density was acquired from a forester involved with management of the hunting area.

As an additional means of verifying processing results a USAETL photo interpreter was given the task of manually counting the trees in each ground truth site, interpreting the same imagery as was used in the digital processing. For each of the Belvoir Hunting Area sites a single interpreted value was provided which represents an intergated stem density for the site. In the case of the forest service image,

no ground truth was available, making photo interpretation the primary method of establishing the "true" value for stem density. Here the interpretation was done over several circular areas providing a mean and standard deviation.

A comparison of stem densities, as derived from all three methods is given in numerical form in table 3, and is duplicated in graphic form in figure 105.

VI. Conclusion

As clearly shown in figure 105, the stem density results varied considerably when derived by the three different methods. Assuming the ground truth values are the most accurate of the three, some interesting trends are apparent. The most universal trend was that whenever large discrepancies occurred, the error committed by computer assisted and by manual interpretation was to underestimate the number of stems, occasionally by as much as 60%. A second noticeable trend was that efforts with winter imagery were much more accurate than those with summer imagery. Dense summer deciduous forests proved the most difficult.

With regard to computer assisted processing there was a definite inverse relationship between the amount of effort expended to do the processing, and with the accuracy of the results. Two of the digitized areas, Stem 3 and Stem 8 consumed at least half of the project effort. Results for these areas were extremely poor, being low by about 60%. Manually interpreted results for these areas were low by only about 15%. In retrospect, serious judgement error was committed with Stem 3 concerning

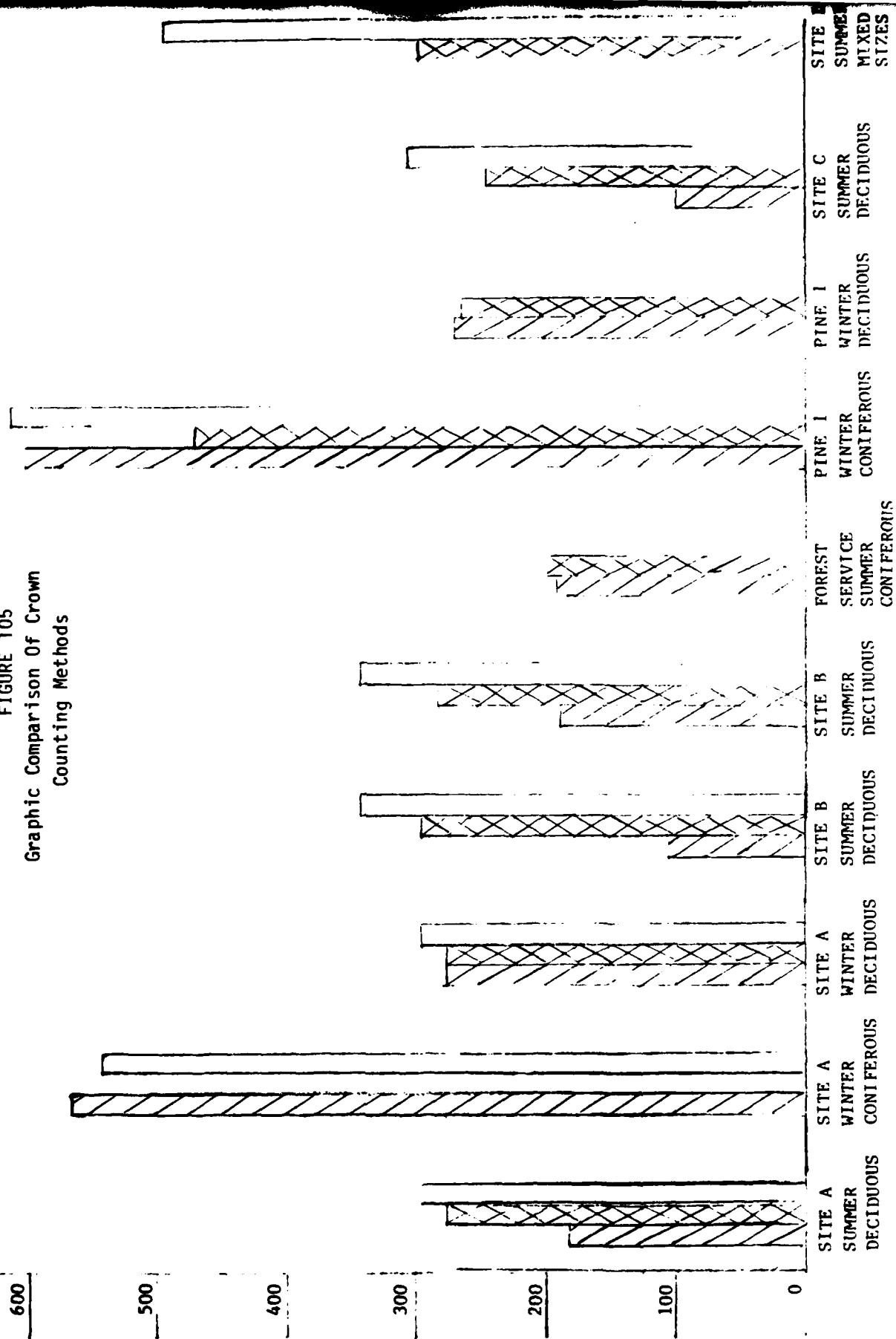
Table 3

Comparison of Tree Crown Counting Methods

Ground Truth Site	Digitized Area #	Image Season	Forest Type	Extracted Stems/ha	Manually Interpreted Stems/ha	Ground Truth Stems/ha
A	7	Late Summer	Deciduous	177	275	290+31
A	15	Late Winter	Coniferous	562	Not Done	544+157
			Deciduous	276	275	290+31
B	8	Late Summer	Mixed Deciduous	104	278	339+63
B	9	Late Summer	Mixed Deciduous	184	278	339+63
Forest Service	10	Summer	Coniferous	189	193+82	Not Done
Pine 1	14	Late Winter	Coniferous	600	468	617
			Deciduous	269	264	Not Done
C	3	Late Summer	Deciduous	98	248	311+94
D	13	Late Summer	Mixed Species & Sizes	Not Done	290	489

EXTRACTED STEMS
MANUALLY INTERPRETED
GROUND TRUTH

FIGURE 105
Graphic Comparison Of Crown
Counting Methods



the scale at which the crown template should be applied. The poor results from Stem 8 came from exceptionally bad crown definition and difficulty in visually interpreting a relatively featureless image segment out of context. On the other hand, when computer assisted processing worked well results were accomplished without a great deal of effort.

Processing results for the areas of coniferous forest investigated can only be described as exceptionally good, whether evaluated by visual inspection or by comparison with ground truth. The processing was judged more accurate than photo interpretation for the forest service image, and corresponded with ground truth to within a few percent for the Fort Belvoir sites.

An unexpected capability of the computer assisted methods was the ease with which stems of deciduous trees could be mapped on winter photographic images. The radially sprayed bare stems represent features with unique spatial characteristics that were easily indentified through the use of a line finding template. Under visual inspection, location of the stems on these images appeared to be nearly perfect, and numerical results agreed closely with manual interpretation and with ground truth.

Based on the images investigated, the computer assisted crown locating techniques appear to be viable, producing accuracies comparable to photo interpretation. For images where crowns are well defined the techniques may be super to manual methods. There are, however, situations where the processing does not work well, and efforts to work these situations are largely a waste. These problem situations

- also exists for manual interpretation, if crowns do not appear as individual features on an image they cannot be accurately counted, they can only be estimated.
- -

IV. Recommendations

While interactive extraction of forest related data is developing as a useful addition to image processing systems, some of the operations used could benefit from further refinement. Experience to date suggests two areas which need to be improved.

The most prominent single error source in the processing sequences tested was the selection of inappropriate scales for the application of the crown locating template. For the analysis of images with well defined crowns, a fairly high tolerance in the scaling of the image relative to the crown template is acceptable, as was proven by the coniferous forest results. With the less distinct deciduous crowns, scale selection is far more critical. In this project phase scales were selected by analyst judgement and in several cases the choice was poor. The process could be significantly upgraded by employing a more serious scale selection method. Computer assisted methods could be used to provide more accurate scale selection with less operator effort. Gross judgement errors, like the one committed on Stem 3 would probably be avoided. Selection of the optimum scale might be done in a fairly automated fashion by interactively designating a uniform forest sample and using Fourier analysis to extract the dominant frequency from the sample. The optimum template scale could then be computed to match this frequency. An alternate and more interactive

method might be to accentuate or classify inter-tree shadow areas and then extract the dominant shadow frequency. For both of these methods an efficient, single dimensional operation would probably be sufficient and might be best applied parallel to the solar azimuth.

An upgrade of the theme filter developed in Phase 2 is also in order. After using the filter on a wide variety of image categorization problems a few minor changes are seen which would significantly increase it's utility. The filter was designed to be versatile and has proven to be so, but it is not particularly easy or fast to set up. Changes should now be made to facilitate the laborious interactive task of constraining the filtering action. Several filtering options have been used heavily, and these options should be menu selectable, using the computer instead of the operator to calculate processing parameters.

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